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Tillage-induced changes in the physical properties of soil

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by

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I. INTRODUCTION

Tillage has been a dominant activity in agriculture from the beginning of civilization. Principal reasons for tillage were to establish and maintain a crop free of weeds (Cannell, 1985), bury plant materials (Sprague, 1986), mix lower horizons with surface layers (Sprague, 1986), loosen the surface for water movement (Unger and Fulton, 1990), aid seed placement, encourage emergence (McCalla, 1967), and reduce weeds, insects and diseases. Changes in tillage procedures, practices, tools, and in tillage terminologies have also occurred with the passage of time. These changes were basically crop-oriented, soil-oriented and labor-oriented. Tillage tools have evolved from rudimentary ones operated by humans to more sophisticated ones powered by animals and, eventually, by machines (Schafer and Johnson, 1982).

When shifting from moldboard plow to a disk, from a cultivator to a rotary tiller, or from extensive tillage to limited tillage, we change the seed environment that is created. In other words, a change in tillage will cause a change in resulting physical properties (Cassel, 1982). These properties include bulk density, soil moisture, and nutrient availability. Tillage operations, regardless of the tillage implement, alter soil physical properties. The soil may be loosened, granulated, compacted, crushed, inverted, sheared, or shattered (Cassel, 1982). In short any manipulation that changes soil condition may be considered tillage, but there is limited information available concerning tillage-induced soil changes (Gantzer and Blake, 1978; Erbach et al., 1986). To understand tillage effects on a given soil physical property, one must also consider the effects on related physical properties (Hill, 1990).

Ehlers (1984) reviewed tillage research and mentioned that little effort has been spent trying to understand how the soil physical factors actually influence plant growth and yield. The same is true for the transmission of external forces within the soil and the effect of these forces on the arrangement of soil particles and pore spaces (Ehlers, 1982). Economic considerations and physical limitations force us to consider, how deep and how much to till. Excess tillage overpulverizes the soil and accelerates the loss of soil moisture and organic matter (Sprague, 1986). Less tillage may reduce yield by not providing the required seed environment (Griffith et al., 1986).

Progress in tillage research has been greatly hindered by the presence of the many soil and weather variables which affect tillage results (Sprague, 1986; Luttrell, 1964). Proper tillage is the least tillage necessary to produce the desired crop (Sprague and Triplett, 1986). Agricultural soils act as a medium in which water, air, and nutrients, are transmitted to seeds and plants, thus, soil parameters that describe the storage and transmission of these entities are of prime importance (Schafer and Johnson, 1982). As Spoor (1975) noted, plants do not respond to the tillage tool directly, but rather, to the soil environment created. Because plant roots provide the contact with the soil that is necessary for the transmission of water, air, and nutrients, to a plant, a soil environment and profile conducive to root growth and proliferation are desirable to maximize plant production. Ehlers (1984) stressed that tillage research should seek to determine how physical factors and processes are changed by tillage and how plants respond to these changes. We can not predict tillage and traffic effects on soil physical properties and processes or predict plant response when we do not understand the complex cause-effect relationships.

Future research on tillage systems must be prescribed for specific crops, soil types, soil conditions, and seed environmental conditions on a narrower geographic scale than is now practiced (Johnson et al., 1980). Thus, effects of changes in soil properties due to tillage should be interpreted from the perspective of the ecological zone (Lal, 1982; Taylor, 1967). Pakistan is a country of varied climate.

The climate ranges from arid to humid. Due to this variation, there is a great difference in sowing and harvesting seasons in different agro-ecological regions (Muhammad, 1982). Wheat is a Rabi crop (winter crop), is the single largest crop in terms of land area, and has an annual production of 15 million metric tons (Ministry of Food and Agriculture, 1987). Present technology for seedbed preparation in Pakistan revolves around the use of a tine-type cultivator traditionally drawn by a pair of bullocks or by a tractor (Afzal et al., 1983). The construction of this implement is such that it leaves untilled soil between the tines and thus necessitates a number of passes for achieving a suitable seedbed. Sheikh et al. (1983) reported lower yields, higher costs, and higher soil shear strengths with tine cultivation as compared to disk and other tillage systems.

Due to the lack of research on the optimum use of tillage implements with different soils, climate conditions and crops, there is a little knowledge on the proper use of tillage implements in Pakistan (Choudhary, 1985; Afzal et al., 1983; and Clarke, 1961). Selection of tillage equipment by farmers is non-scientific, and more or less dependent upon market availability.

II. OBJECTIVES

Specific objectives of this study were:

1. To determine effects of different tillage systems on selected soil physical properties.

2. To compare measured plant emergence and yield differences among these tillage systems and to relate crop response with tillage-induced soil physical changes.

III. LITERATURE REVIEW

The art of tillage began when man first domesticated and cultivated plants (Schafer and Johnson, 1982). Early assumptions (Baver, 1932; Baver, 1956; Keen, 1931) are that tillage was used to improve the productiveness of soil because tillage produced small clods and soil particles which provide more surface contact area for seeds and plant roots to obtain moisture and nutrients. In the early 1930s, Slipher (1932) cited tillage as a way to manage and control soil structure. Concern for the amount of tillage and the type of tillage also emerged. Yoder (1937), described the ultimate goal of tillage as a "high state of tilth and the attainment of this goal rests in the art of tillage". During the same period, Baver (1932) related soil physical properties to the soil cultivation and tillage implements. Later Russell (1949), Browning (1950), Nichols and Reaves (1955) and others, emphasized and reported the importance of tillage induced changes on soil physical properties. They stated that optimum results with a particular tillage machine can be obtained only when the soil is in a specific physical condition. Literature available in this field is voluminous. This review includes selected references considered to be pertinent to the present study.

A. Soil Properties as Affected by Tillage

1. Bulk Density

One soil physical property that is nearly always altered by tillage operations is bulk density (Cassel, 1982). This has often been used as one measure of the effects of tillage practices. Density is a temporary condition that changes with time and rainfall. In field studies, density measurements exhibit both spatial and temporal variability (Cassel, 1982). The spatial variability results from vertical and lateral changes in soil properties such as texture, structure, and organic matter content and from the effects of past soil management practices. The temporal variability occurs after a tillage system is applied. To account for positional effects of tillage, bulk density as a function of both depth and position may be studied (van Diepen, 1980). Position is defined as the perpendicular or normal distance from the crop row (Hageman and Shrader, 1979). Data from two dates may demonstrate the temporal changes (Tiarks et al., 1974). Therefore, extreme caution must be exercised when analyzing bulk density data collected on different dates. Temporal variation in bulk density of freshly tilled, nontrafficked soil occurs due to shrinking and swelling of the soil (Berndt and Coughlan, 1976).

The range in density required for optimum plant growth is unknown for most soils. Density lower than optimum reduces water holding capacity, and higher bulk density leads to poor aeration which may limit root extension (Cassel, 1982). Tillage generally tends to decrease the density and increase the total porosity of the surface soil (Croney and Coleman, 1954). At the same time, the soil just below the plowed or tilled layer may become more dense due to the stresses applied to that layer by tillage machinery. The pore space geometry produced in the surface soil is usually very unstable and changes of the pore geometry with time are common (Klute, 1982). Statistically significant differences in density changes by tillage have been recorded but the effects of this density change on plant growth and/or yields are not well understood (Flocker et al., 1960; Singh et al., 1971).

Results of tillage and no-tillage treatments on bulk density are not consistent and at times are contradictory, as reported by Hill and Cruse (1985). Some researchers have observed significant differences in soil bulk density under conventional and conservation tillage treatments (Dickey et al., 1983; Mulvaney and Paul, 1984; Unger and Stewart, 1988), whereas other researchers (Blevins et al., 1977; Tollner et al, 1984; Shear and Moschler, 1969) found nonsignificant differences.

Core sampling has long been used for measuring soil bulk density (Voorhees and Lindstorm, 1984). Undisturbed core samples have been used successfully for the determination of bulk density of undisturbed soil or soil which has settled to a firm condition (Buchele, 1961). But, difficulties arise in determining the bulk density of freshly disturbed soil. Published bulk density values from tillage studies, based upon soil core samples, range from <1.0 to >1.7 Mg/m^3. Significant differences in bulk density among tillage treatments as small as 0.07 Mg/m^3 have been reported (Cassel, 1982).

2. <u>Moisture Content</u>

Tillage destroys the macropores that promote the downward movement of water and otherwise alters the pore geometry of the soil medium (Bowen and Coble, 1967). The pore space geometry produced in the surface soil is usually very unstable and changes of this geometry with time are common (van Doren, 1967). Soil is a porous medium which contains various sizes of pores. Water entering the soil either remains in the pores or percolates through to lower depths. Tillage influences the pore sizes and their arrangement, which in turn affects the storage and movement of water within the soil. Because tillage can create an aggregated condition of the soil, effect of aggregates is well considered by Wittmus and Mazurak

(1958), Farrell (1972), Tamboli et al. (1964), Amemiya (1965), and Klute (1982). From these studies, it appears that a packing of aggregates of a given size range will hold more water at zero suction than a packing of primary particles of the same size range. This is due to the additional porosity within the aggregates. Lal (1986) related tillage and seedbed requirements to soil properties and constraints. He emphasized that soils with similar physical characteristics may respond differently to tillage methods depending on the prevailing soil moisture regime. Conversely soils with a similar moisture regime may require different tillage because of variations in their physical properties.

Water movement and storage play a central role in the physical soil processes involved in crop responses to soil cultivation (Hamblin, 1982; Goss et al., 1978). Soil water largely influences soil temperature, mechanical resistance and aeration. It is usually difficult to detect the real cause of an effect on a crop, but the primary cause of many effects is associated with water in the soil or on the soil surface (Kuipers, 1984).

3. Penetration Resistance

Another important parameter usually reported in tillage research is the measurement of soil strength. Lindstrom et al., (1984) reported consistently greater penetration resistance of soils under conservation tillage than soils under conventional tillage. Rizvi et al. (1987) reported no difference of penetration resistance in no-tillage and chiseled treatments, but their penetrometer readings showed increasing values during the later part of the corn growing season compared to the resistance values just after tillage. They also reported significantly higher penetration resistance with depth under both tillage practices. Mazurak and Pohlman,(1968) observed that soil strength has minimal effect on root elongation unless the cone index value exceeds 400 kPa. Soil strength has been shown to increase with increasing bulk density and decreasing soil matric potential, but not independently (Hill, 1990).

Values of penetration resistance at in situ field capacity, as measured by the cone penetrometer and reported as the cone index, range from zero in a subsoil slit to values >900 kPa in a tillage-induced pan (Cassel, 1982). The Cone Index is defined by ASAE standard S313.2 (ASAE, 1990) as the force required to push a metal cone of specified geometry into the soil, divided by the base area of the cone. For proper interpretation of penetration resistance data, related soil physical properties data must be made available (Cassel, 1982). Hence, whenever penetration resistance measurements are taken, it is also necessary to collect soil water content and bulk density data. Penetration resistance generally increases with both bulk density and matric potential (Singh and Ghildyal, 1977). Other factors affecting penetration resistance are texture, structure, and particle surface roughness (Cruse et al., 1980). It is important to select an appropriate time to measure penetration resistance. Chancellor (1976) recommended that penetration resistance measurements be taken when the soil is at in situ field capacity. The shape of the tip (cone-shaped vs blunt), cone angle, cone diameter, and penetration rate are factors which affect measured values (Jezequel, 1969; Gooderham, 1976; Freitag, 1967; Bowen, 1976). Penetration resistance also may vary both spatially and temporally (Cassel, 1982).

Sial (1987) reviewed literature concerning the relative sensitivity of cone resistance and bulk density methods of measuring tillage responses in soils. He discussed Ronai's 1982 claim that bulk density is a more appropriate parameter to characterize soil compaction than penetration resistance. However, Voorhees et al. (1978) compared these techniques in a five year study and found that bulk density increased by 20% or less while the corresponding increases of penetration resistance were up to 400%, indicating a higher sensitivity of cone index measurements. Similarly, Carter and Tavernetti

(1968) considered the use of cone penetrometer resistance superior to bulk density measurements.

4. Soil Temperature

The temperature of the soil is thus a factor of vital concern (Scharringa, 1976). Soil temperature affects seed germination, plant emergence, root growth, nutrient uptake, and plant development. Soil temperature affects plant growth indirectly through its effects on soil water, aeration, soil structure, nutrient availability and decomposition of plant residues (Wierenga et al., 1982). Often, soil temperature is the determining factor in plant production. Many crops cannot be grown unless the soil temperature is above a minimal level; in tropical areas, soil temperatures may be too high for growth of some crops. Furthermore, the range of optimal soil temperatures for crop production is rather narrow, compared with those of other soil physical properties (Wierenga et al., 1982). A 2 to 4 degree change in soil temperature can affect corn growth by as much as 30% (Cruse, 1985).

Soil temperature is a function of the net amount of heat that enters or leaves the soil. The amount of heat that enters or leaves the soil surface is dependent on radiation in soil heat flux, convective heat and latent heat (Cruse et al., 1982). The color, roughness, exposure, thermal conductivity, and water content of the surface soil layer all have an effect on the amount of heat entering the soil. Tillage or loosening of the upper soil layer by mechanical means changes the thermal conductivity of this layer (Wierenga et al., 1982). Frequently, its color, roughness, and water content change also.

Different tillage systems have different effects on the soil temperature regime, because they affect soil physical properties such as porosity and water content differently (van Doren and Allmaras, 1978). Loosening the top soil layer reduces the heat uptake and heat loss of a soil, and causes more heat exchange to take place in the surface soil (van Doren, 1956). The effect of tillage on soil temperature is complex, and tillage may either increase or decrease soil temperature, depending on the depths and times of the year considered. Measurements are usually made at several depths in differently treated plots, and in several replications (Hillel, 1980). Harmonic analysis has been used by some researchers to describe temperature variations in soil (van Wijk, 1963; Nerpin and Chudnovskii, 1970; Carson, 1963; Kalma, 1971). Observations of soil temperature help to characterize the effects of tillage on the physical condition of the soil profile related to crop production.

A difference of only 1 hour in reading of the thermometers in one plot vs another may yield significant and consistent differences in temperature not related to the treatments (Wierenga, et al., 1982). Soil moisture exerts an influence on soil temperature, by varying the specific heat of the soil, by encouraging heat conduction, and through surface evaporation and through percolation.

5. Surface Roughness

Water, air, and energy enter and exit the soil at the soil-atmosphere interface. This transfer is influenced by soil-surface characteristics. Transfer at the soil-atmosphere interface indirectly depends on the surface geometry (Schafer et al., 1985). Surface roughness is influenced by tillage, and has been extensively studied, as reviewed by Soane (1975). The standard deviation of elevations (sigma) is frequently used as an index of roughness, with a higher sigma occurring on rougher surfaces (Linden, 1982). Because tillage affects roughness, it also affects the area of the soil directly in contact with the atmosphere. Tillage tools such as plows and subsoilers tend to create rougher soil surfaces than tools like harrows or powered rotary tillers. The tillage systems that produce the largest clods, lowest bulk density, and roughest surface also produce the greatest macro-porosity.

The micro-porosity may be increased with tillage operations that produce small soil clods (Lovely, 1967).

The degree of roughness must be determined by the magnitude, form and spacing of irregularities on the surface of soil after tillage. It is evident that no single figure or dimensional value will represent precisely the roughness. Hydell (1960) introduced roughness as the average deviation of the surface profile from the mean centerline through the surface. Typical studies of soil surface roughness induced by tillage tools are those of Luttrell et al., (1964), Allmaras et al., (1966), and Currence and Lovely (1970). Typical values of random roughness, as defined by Allmaras et al., (1966), ranged, in their studies, from about 5 mm before tillage to about 30 mm after moldboard plowing. Allmaras et al. (1977) reported that random roughness on the plowed surfaces of a clay loam soil was reduced as much as 40% by rainfall. Thus, both tillage and climatic forces influence surface characteristics.

6. Clod Size Distribution

A major reason for tillage is to create soil physical conditions that are conducive to good seed germination (Gupta and Larson, 1982). Generally, this means desirable temperatures and favorable water and aeration conditions in the seed zone for a given plant species. Soil physical conditions, in turn, affect microbial activity, root growth, and other biological processes in the soil. During tillage, a part of the soil is broken into various size clods by the implements; depending upon the soil type, water content at the time of tillage, and stresses exerted by the tillage implements and equipment, soils are affected differently by the breakup processes. Allmaras et al. (1965) showed that the geometric mean diameter of aggregates in the row zone varies with the type of tillage and the type of soil. The degree of soil breakup that is optimum for plant growth depends upon the seed size, the crop type, and the soil and weather conditions (Gupta and Larson, 1982). Larson and Swan (1970) suggested an average aggregate diameter of 6 mm in the row zone of wet soils for corn. They indicated that with most planters, this would produce good packing over the seed at a water content favorable for germination. For dry soil, they suggested use of furrow openers to place the seed in moist soil and a bed of 2 to 6 mm aggregates at the soil surface to slow evaporation. Russell (1973) and Dexter (1988) have shown that the optimum seedbed is composed of aggregates with a size range between 1 and 5 mm diameter in the vicinity of the seed.

Tillage machine features such as size, shape, sharpness, and speed of operation do affect clod size. However, the resulting clod size is determined to a far greater extent by the soil type and condition at the time the tillage operation is performed. Plowing when the soil is too wet, "near field capacity", or when it is too dry, "below the wilting point", usually produces large clods. This same operation when the soil is midway between field capacity and the wilting point will frequently produce a finely pulverized soil consisting of small clods (Lovely, 1967).

Roughness, like clod size, is more a function of soil conditions than machine features. However, tillage tools such as plows and subsoilers tend to create rougher soil surfaces than tools like harrows or powered rotary tillers (Lovely, 1967).

Cole (1939) studied changes in the size distribution of aggregates after tillage operations and found plowing caused a decrease in clod size unless performed at excessive moisture contents. Lyles and Woodruff (1962) studied the effect of moisture and tillage on soil clod size. They found that type of implement had a decided influence on the size and stability of clods formed. The resulting differences caused by changes in tillage implements persisted longer than those due to variable moisture content. A moldboard plow produced more large clods and fewer fine particles, than the one way disk or the sub-surface sweep.

B. Crop Performance as Affected by Tillage

1. Seedling Emergence

Stand establishment is regarded as the single most important stage of growth in the life of a crop, and is the most vulnerable stage of development. The primary function of seedbed preparation is to create an environment for rapid crop growth that approaches an optimum (Sprague and Triplett, 1986). The vigor of the young seedlings influences the development of the crop throughout its entire life. A germinating seed contains a limited pool of reserve food for support during the period of establishment.

There have been few research attempts to define the best seedbed in terms of seed germination and emergence. An Indiana study concluded that a seedbed containing 20-30% of its aggregates smaller than 2 mm in diameter is well suited to corn germination (Mannering et al., 1975). Of the four tillage systems studied (plow, chisel, till-plant, and no-tillage), till-plant most consistently provided this aggregate range and the best germination on five soil types ranging from sandy loam to silty clay loam. When aggregates of this size were below 15%, germination was lowered. Greater than 30% small aggregates (<2 mm) caused increased soil crusting and reduced seedling emergence.

Seedbed preparation is of concern when choosing a tillage system because of its importance to seedling establishment, which determines in large part the subsequent growth of the crop. No one system is suitable for all crops and situations; none are simple or equally successful on all counts (Triplett, 1986).

Seedling emergence is affected by the mechanical resistance of the soil to seedling penetration. Bowen (1966) showed that mechanical soil impedance above 76 kPa restricted the emergence of cotton seedlings. Feldman and Domier (1970) observed that by increasing the soil contact pressure from 103 to 276 kPa, cone penetration resistance increased by 23% and the corresponding reduction in wheat stand was 27%.

2. <u>Crop Yields</u>

Crops respond to changes in soil water content, soil temperature, nutrient supply, composition of the soil atmosphere, and to the strength of the soil. The specific tillage practices employed influence all these plant growth factors, although the effects may be different for different soils and weather conditions (Larson and Osborne, 1982).

Phillips and Phillips (1984) concluded that reduced tillage may decrease, increase, or have no effect on yields compared with yields obtained with conventional tillage methods. Similarly, other studies of the effects of tillage implements on yields, reported contradictory results. Erbach et al. (1986) reported no significant yield effect among the no-till, spring disk, and fall moldboard plow for the first year, but observed significant yield differences in maize yield in the order: no-till <spring disk <fall moldboard plow, for the second year. Sheikh (1983) and Khan et al. (1986) reported better wheat yields with a disk and moldboard plow compared to a cultivator. Identifying the effect of tillage on soil physical properties will facilitate the understanding of how tillage affects crop growth and yield.

Wheat following rice usually suffers from the poor soil physical environment of a puddled flooded soil. Although, favorable for the rice, it is considered undesirable for the optimum growth of wheat. In the fields where rice was grown before wheat, Majid et al. (1987) reported the highest grain yield of 5.58 t/ha in moldboard plowed plots which was 28% higher than the cultivator, chisel, and local plow. Similar yield increases were recorded by Chancy and Kamprath (1982), Kamprath et al. (1979), Costamagna et al. (1982) and Lindemann et al. (1982).

Kosanskii (1979) reviewed the literature on the influence of different cultivation factors on changes in the physical properties of the soil, and he reported that in the majority of cases these investigations did not succeed in providing the existence of a relationship between changes in particular physical properties of soil and crop yield. He concluded that these physical properties, of a dynamic and complex nature, cause a change in the direction of the effects of other properties which, in turn, influence still other properties, and so on.

The effects of tillage on crop response depend on soil, climate, tillage implement used, and topography (Raghavan et al., 1983). In combined compaction-tillage experiments (Quebec, humid climate), Negi et al. (1981) found that the highest yields were obtained on compacted but subsequently chiseled or moldboard plowed plots on both a sandy and a clay soil.

IV. MATERIALS AND METHODS

A. Description of Sites

This research was conducted at three agro-ecologically different sites in Pakistan. The sites were at the National Agricultural Research Center (Islamabad), the Agricultural Engineering Research Farm (Faisalabad), and the Cereal Crops Research Institute (Pirsabaq). Wheat-fallow, sorghum-fallow rotation had been used previously at Islamabad, a wheat and rice had been grown in rotation on Faisalabad, and at Pirsabaq, wheat and maize rotation was followed. Soils at Islamabad and Faisalabad were clay loam and at Pirsabq was sandy clay loam. Particle size distributions were determined by the pipette method (Walter et al., 1978) for each site and are given in Table 1. The sites were located on the Barani lands (Region V), lower Northern Irrigated Plain (Region IVa), and upper Northern Irrigated Plain (Region IVb) respectively. These are three of the twelve agro-ecological regions and sub-regions of Pakistan, shown in Figure 1. The regions are classified on the basis of physiography, climate, soils, and land use (Agro-ecological Regions of Pakistan, 1980). Additional information regarding the three sites is given in Table 2.

Table 1. Soil particle size analysis

Site	Particle size (in millimeters)			Soil textural class
	Sand 2-0.05	Silt 0.05-0.002	Clay <0.002	
	%	%	%	
Islamabad	37.8	29.6	32.6	Clay Loam
Faisalabad	31.6	31.8	28.6	Clay Loam
Pirsabaq	53.6	23.8	22.6	Sandy Clay Loam

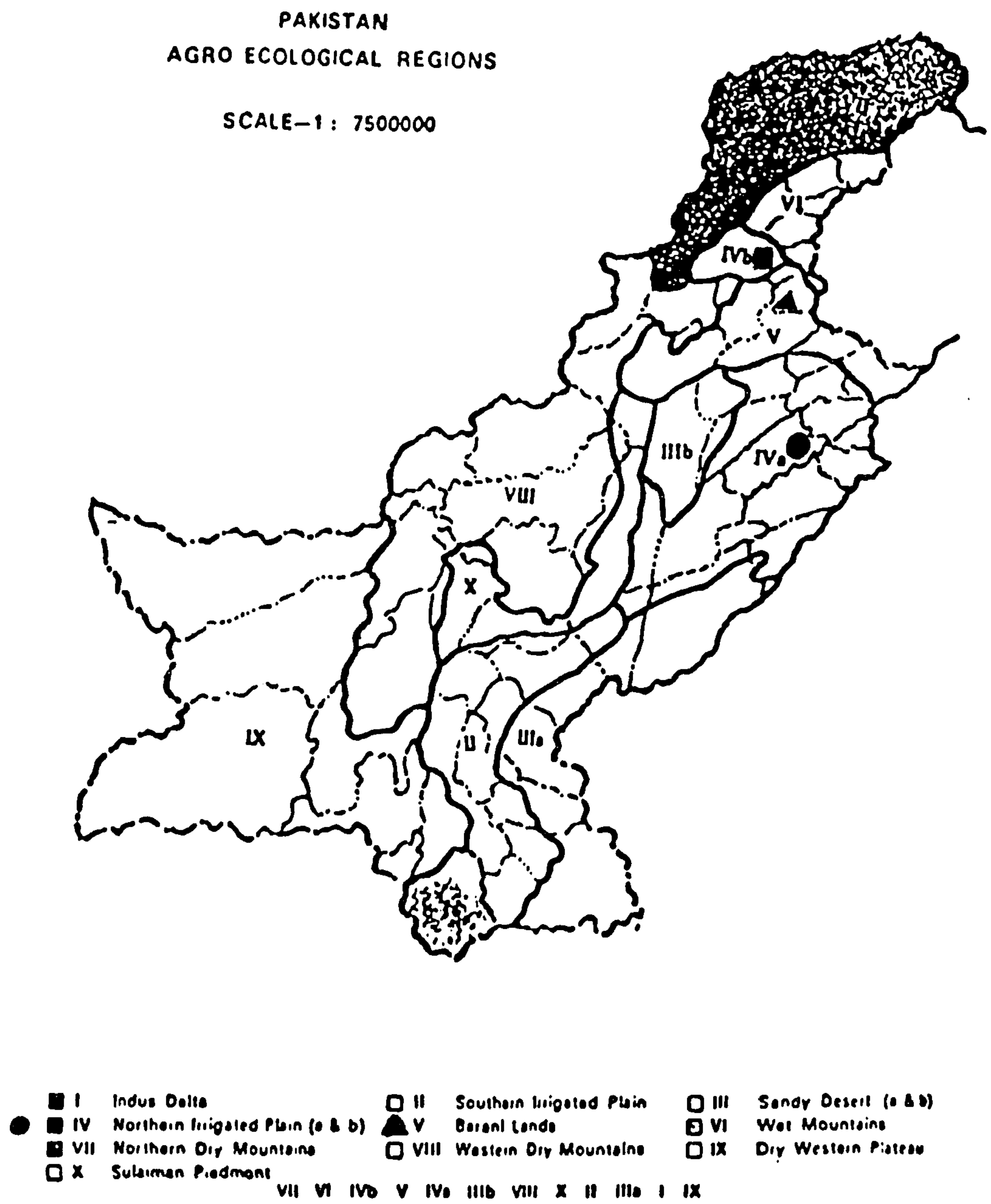

Figure 1. Agro-ecological regions and sub-regions of Pakistan

Table 2. Information regarding the experimental sites

Parameter	Islamabad	Faisalabad	Pirsabaq
Region	Region V	Region IVa	Region IVb
Climate	Humid Cool	Semi-arid Warm	Sub-humid Cool
Rainfall (mm)	1000 or more	250-500	500-1000
Location			
Latitude (°)	33.8 N	31.4 N	34.0 N
Longitude(°)	73.2 E	73.0 E	72.0 E
Elevation(m)	300-600	150-250	150-250
Mean Daily Temperature			
Winter (°C)	5-10	10-15	5-10
Summer (°C)	25-30	30-35	25-30
Major crops	Wheat Maize	Wheat Rice Cotton	Wheat Sugarcane

Pakistan is a country of varied climate, ranging from arid to humid. Due to this variation in the climate, sowing and harvesting seasons occur at quite different times in the different agro-ecological regions.

1. Region V: Barani Lands (Islamabad)

The region covers the Salt Range, Potwar Plateau and Himalayan Piedmont plain. The Salt Range separates the Potwar Plateau from the Indus Plain, and Salt Range valleys are filled with silty and loamy material. The Potwar Plateau has mainly loess deposits. This zone can be best described by dividing it into two regions. A small narrow belt lying along the foot of the mountains is humid. Trial field was located on this belt, about 7 km east of the capital city, Islamabad, at an altitude of 520 m. The area enjoys a pleasant climate. The average maximum daily winter temperature is 16.7°C, and average minimum is 3.4°C. In summer these average temperatures are 34.2°C, and 24.4°C. The average annual rainfall is about 1000 mm. Soils vary from silt loams,to silty clay loams, to clay loams with weak sub-angular blocky structure and good porosity. Its geographic and cultivated areas are 4.8 and 2.5 million ha, respectively. The cropping intensity is nearly 84 per cent. Rainfed cultivation is practiced in most of this region. The main crops are wheat and millet. Some areas, mostly in the eastern part, are irrigated.

2. Region IV(a): Lower Northern Irrigated Plain (Faisalabad) The land lying between Sutlej and Jhelum rivers comprising the Rechna, Chaj, and Bari Doabs is one of the most important agricultural areas of the country. The Doabs are relatively flat lands, but there are remnants of old river channels. This region can be divided into two parts. The eastern half has a semi-arid, sub-tropical, continental type of climate. The western portion, where field plots were located, has an arid, sub-tropical, continental climate. Faisalabad was approximately 375 km from Islamabad, at an altitude of 215 m. The average maximum daily temperature in winter is 15°C, and average minimum 10°C; in summer these average temperature are 35°C, and 30°C. Average rainfall totals approximately 462 mm. The soils in this area are sandy loam to clay loam. The soils are deep and have 0.4 to 0.6 per cent organic matter and a pH around 8.2. They have weak structure but good porosity and permeability. This is the main irrigated area in the Punjab province with a 9.8 million ha geographic area and a 6.2 million ha cultivated area. The main crops are cotton, sugarcane, maize and wheat.

3. Region IV(b): Upper Northern Irrigated Plain (Pirsabaq) The districts of Peshawar and Mardan in the northern part of the country constitute this sub-region. The alluvial valley

of Peshawar is drained by the perennial river, Kabul. Most of this valley has a network of torrents and hill stream beds. Most of this area has a semi-arid, sub-tropical, continental type of climate, but the experiment site falls close to the sub-humid climate area, with rain both in winter and summer. This site was situated 135 km from Islamabad, at an altitude of 344 m. The average maximum daily temperature in winter is 10°C, and average daily minimum is 5°C; average annual rainfall is about 830 mm. The soils of the central part of the valley in this region are clayey and have about 0.6 per cent organic matter. Soils are mostly non-calcareous or moderately calcareous, with a pH around 8.0. This region is one of the most intensively cultivated areas of the country. Canal irrigated farming is the predominant land use and the main crops are sugarcane, maize, tobacco, wheat and berseem. This region's geographic and cultivated areas are 0.71 and 0.28 million ha, respectively.

B. Description of Tillage Equipment

Tillage equipment consisting of a field cultivator, rotary tiller, disk harrow, and a moldboard plow was used. The same tillage equipment was used at all sites.

1. Field Cultivator

The field cultivator used had 11 tines, spaced 10 cm apart on a fixed rigid frame. It was mounted on a Massey-Ferguson 265 model tractor and operated at an average speed of 5.2 km/hr. Two rows of reversible shovels, 6 in front and 5 at the rear were used.

2. Rotavator

A rotary tiller, commonly called a rotavator (Howard), with a width of 0.9 m was used for this study at all sites. It was mounted on the tractor 3-point hitch and operated at a PTO speed of 540 rpm. The tiller rotation axis was at right angles to the direction of travel. Three pairs of L-shaped blades per flange were used. The average forward speed was 3.5 km/hr.

3. Disk Harrow

A 1.32 m wide tandem disk harrow, having 12 disks spaced at 22 cm was used. Front gang notched discs 0.76 m in diameter were used and plain discs 0.57 m in diameter made up the rear gangs. The disk angle was 18 degrees from the direction of travel. The disk harrow was mounted on the MF 265 (Messey Ferguson) tractor and was operated at an average forward speed of 6.6 km/hr.

4. Moldboard Plow

A 3-bottom, general purpose, mounted, moldboard plow was used. Total width was 1.2 m, and each bottom was 0.4 m wide. Each bottom was attached to a standard, which in turn was fastened to the plow frame. Average forward speed was 3.5km/hr.

C. Description of Sampling Equipment

1. Soil Core Sampler

Figure 2 shows a soil core sampler used in this study. The device was designed to obtain 3 undisturbed 7.6 cm diameter core samples at depths of 0-5, 5-10, and 10-15 cm. Three 5 cm high inserts were driven into the soil with a hammer provided with the sampler.

2. Cone Penetrometer

Figure 3 shows a hand held cone penetrometer used in this study. It was equipped with a dial scale calibrated directly in N/cm^2. Length of the shaft was 0.61 m, graduated at 2.54 cm increments. A 30° circular stainless steel cone with 9.5 mm driving shaft, having base diameter of 12.83 mm and base area of 1.3 cm^2 was used (ASAE, 1982). Penetrometer readings were made at depth increments of 5 cm.

Figure 2. Core sampler, inserts, and the plastic covers

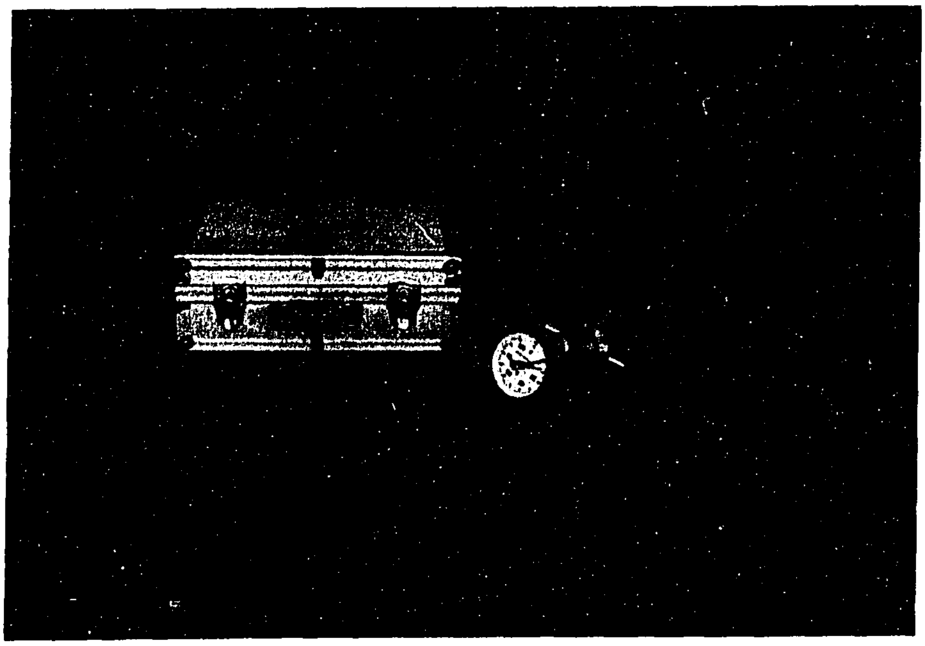

Figure 3. Hand held cone penetrometer

3. Digital Thermometer

A digital thermometer was used in this study. It was provided with a soil probe. This probe when inserted into the soil, caused the soil temperature to be digitally displayed (Figure 4).

4. Depth Meter

Figure 5 shows a simple instrument used to measure the depth of tillage. This depth meter design was a modified version of the depth meter design discussed in RNAM (Regional Network for Agricultural Machinery) Test Codes and Procedures for Farm Machinery (1983). It consists of a slide plate with different holes 7.6 cm apart. Graduated pins were provided to drop from the holes vertically down when the sliding plate was kept horizontally level with the untilled ground.

5. Profilometer

Figure 6 shows the profilometer used to measure soil surface roughness changes from before to after tillage. The meter provided a quick method for obtaining representative samples of the surface profile. Similar profilometer designs were used by Soomro et al. (1982) and Allmaras et al. (1966). The profilometer was placed on the soil surface, and after leveling, the 19 pins were dropped, which then provided a

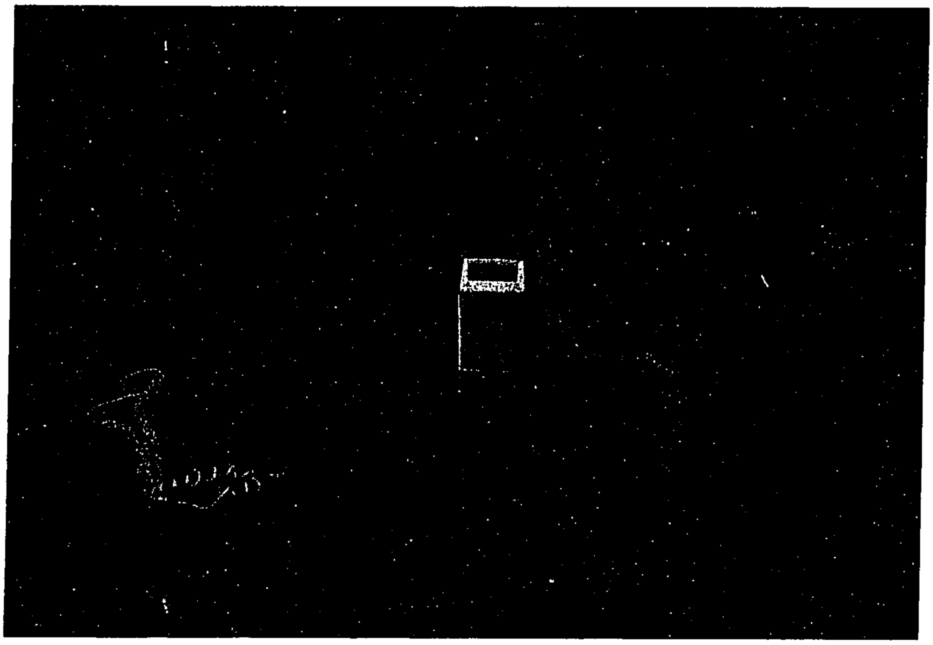

Figure 4. Digital thermometer and the probes

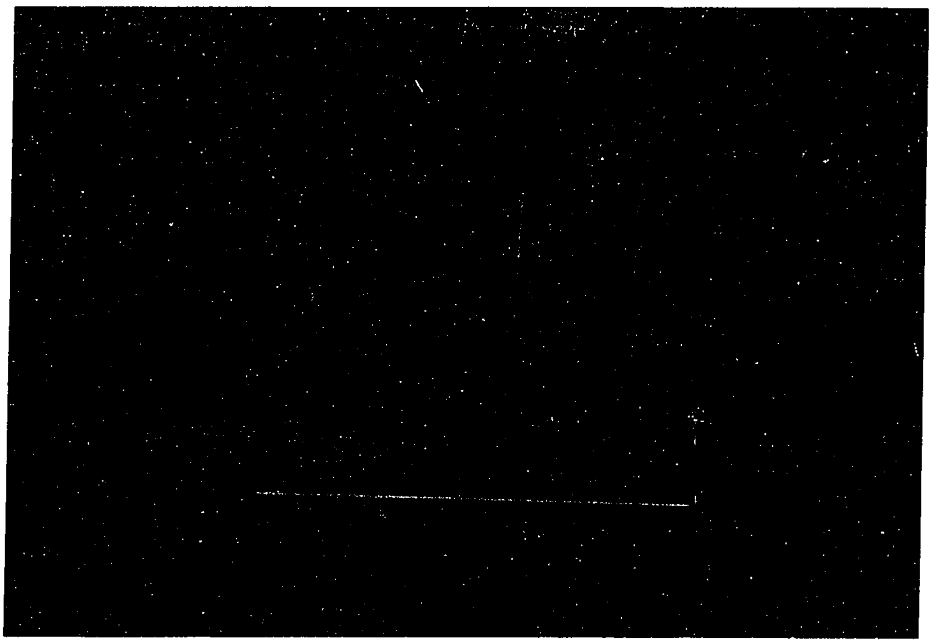

Figure 5. Depth meter with pins

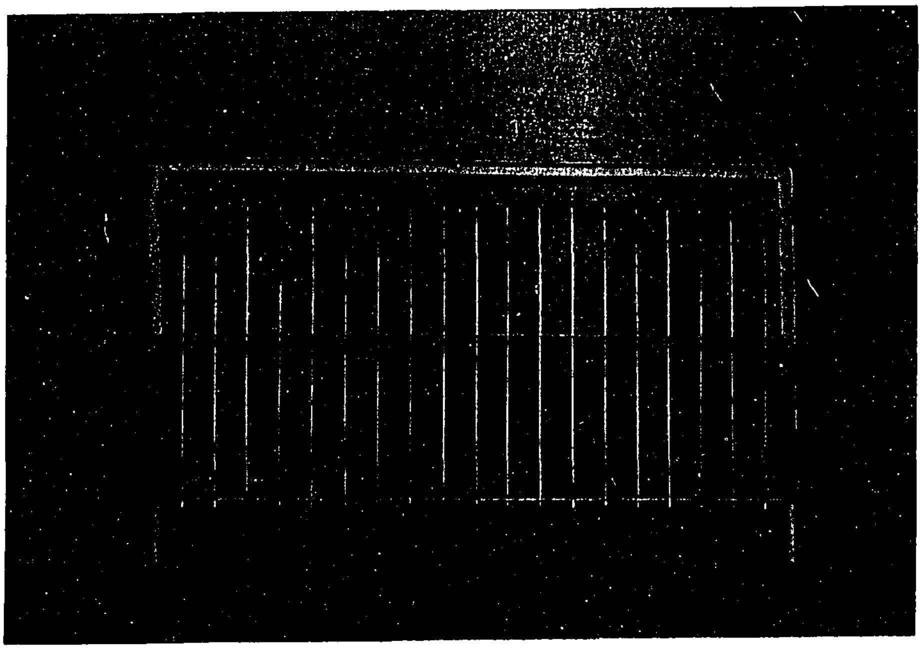

Figure 6. Profilometer used for surface roughness measurements

representation of the profile of the soil surface. Pin heights were recorded and the standard deviation was calculated. A higher standard deviation indicated a rougher surface.

6. Clod size distribution sampling equipment

Figure 7 shows the equipment made and used for obtaining soil samples. The design was adapted from Luttrell et al. (1964). The cylinder was 30 cm in diameter and was made from 20 gage galvanized sheet metal. The bottom edge of the cylinder was sharpened and a depth mark was placed on the side. The cylinder was forced into the tilled layer of the soil to tillage depth. A sufficient amount of soil was removed from around the cylinder to permit the bottom of the U-shaped sheet metal tray to be pushed under the cylinder and act as a bottom to the sampling cylinder. All of the samples were transported from the field to a sieve stand located in a laboratory for separation of the clods. Figure 8 shows the sieves used for clod size distribution. A set of sieves based on the Japan Test Code (RNAM, 1983) was selected, i.e. sieves with 10, 20, 30, 40, 50, 60, and 70 mm diameter openings. The soil sample was passed through a set of sieves, and the soil retained on the each sieve was weighed, as well as the soil that passed through the smallest aperture sieve. These sieves

Figure 7. Soil Sampling cylinder and U-shaped tray used for collecting clod samples

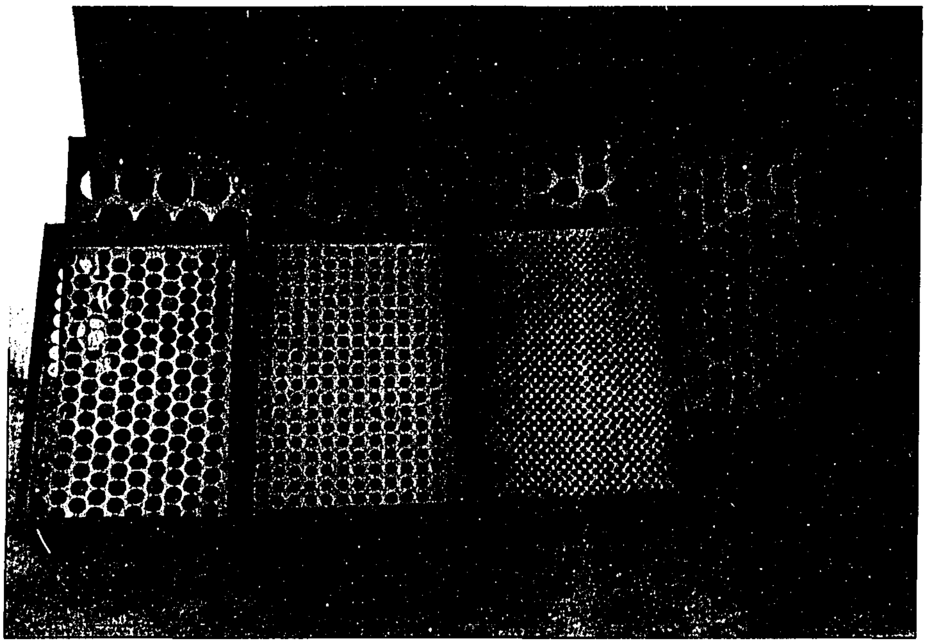

Figure 8. Set of sieves used for clod size analysis

were mounted on a frame, which was shaken with a cam mechanism by turning a handle at constant speed. After the sample was separated into the respective clod size groups, soil on each sieve was weighed and recorded. The MWD (Mean Weight Diameter) of the individual sample was calculated.

D. Experimental Design

A completely randomized experimental design with three replications was used. The four tillage treatments were randomly assigned to twelve main plots. Bulk density, penetration resistance, and moisture content were also measured at three depths, considered as sub-plots, within each main plot. The four tillage treatments, were; cultivator (5 times), rotary tiller (once), disking (twice) and moldboard plow plus disking. Duncan's multiple range test was used whenever a significant F-statistic was found, to test for significant differences between treatment means.

E. Procedure Description

Figures 9, 10, and 11 show the plot layouts at the National Agricultural Research Center, Islamabad (Humid), the Agricultural Engineering Research Farm, Faisalabad (Semi-arid), and the Cereal Crops Research Institute, Pirsabaq,

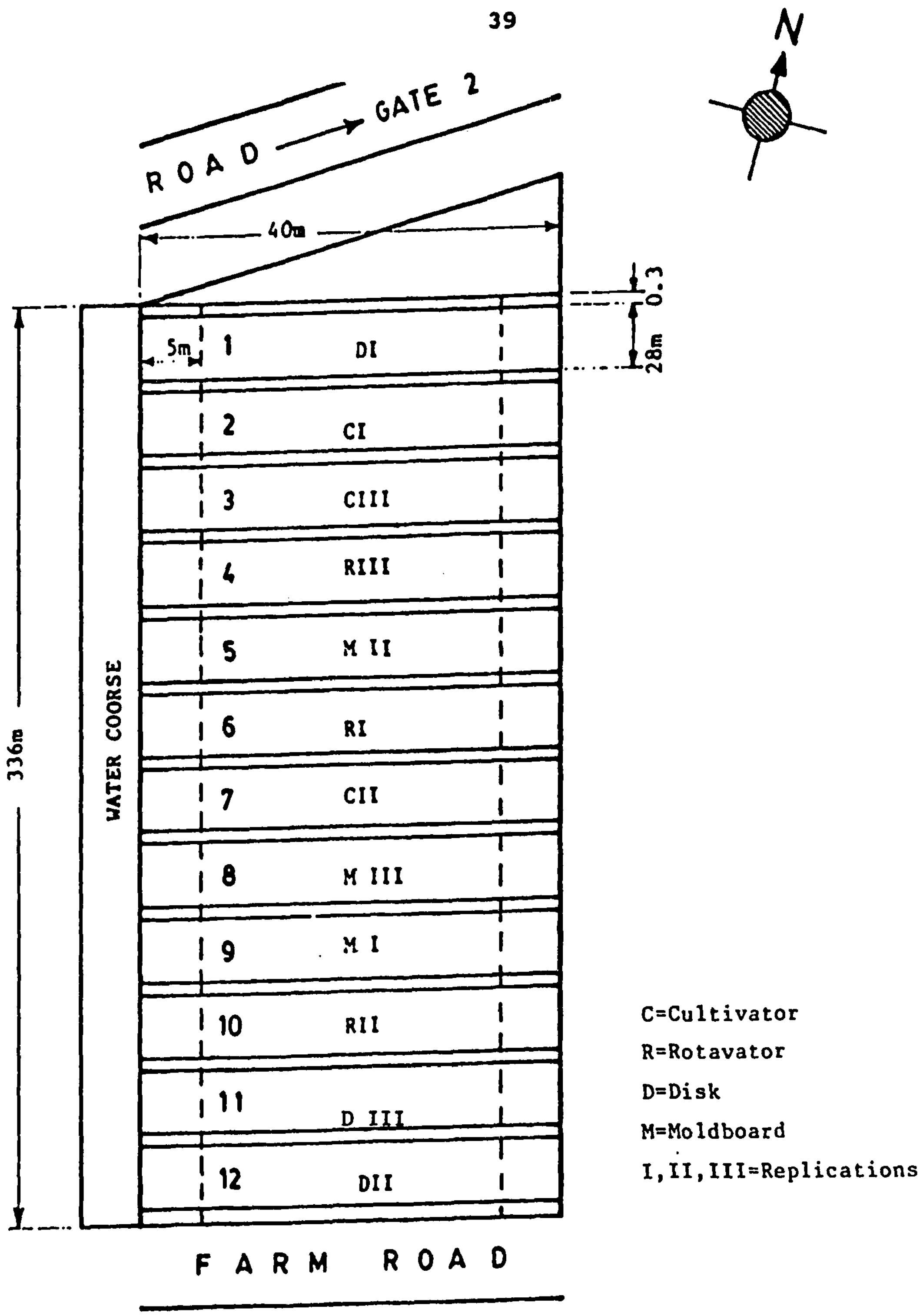

Figure 9. Plot layout at Islamabad (Humid)

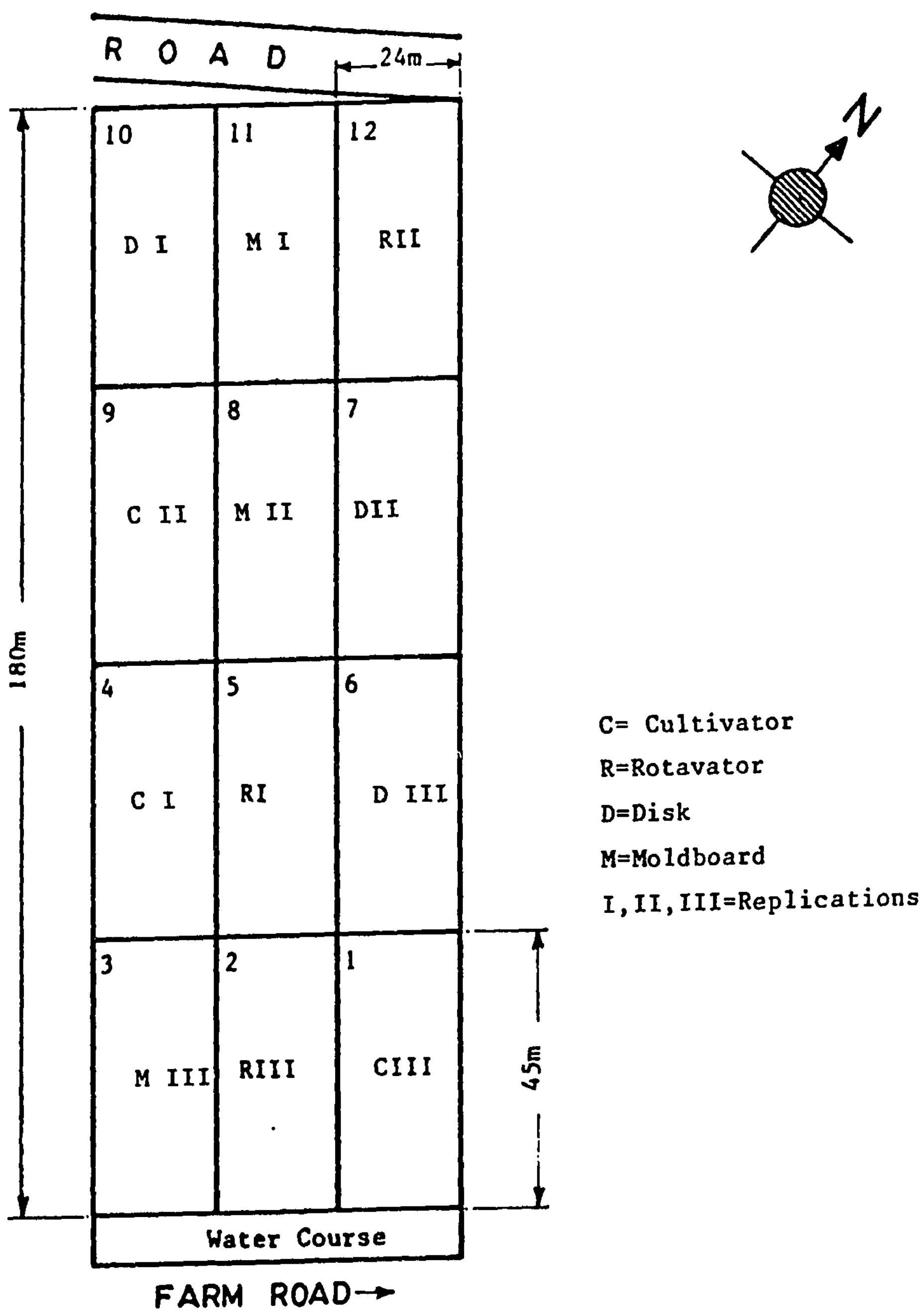

Figure 10. Plot layout at Faisalabad (Semi-arid)

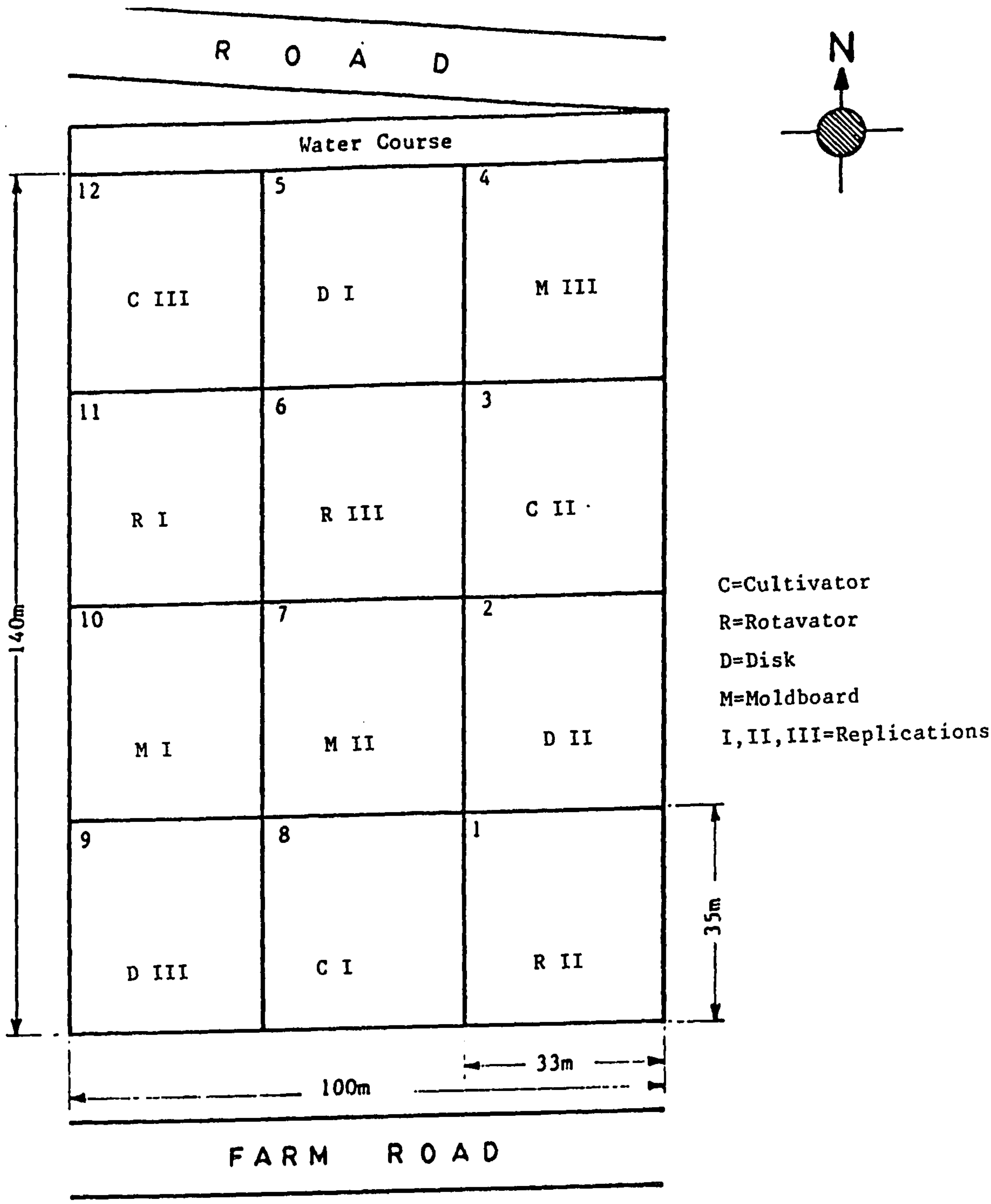

Figure 11. Plot layout at Pirsabaq (Sub-humid)

(Sub-humid) respectively. Individual tillage plots at each site were rectangular and contained 0.15 ha each. Row spacing of 18 cm and plant spacing of 6-8 cm within rows was used. Wheat (Triticum aestivum L.) was grown at all sites.

Fertilizer was applied at the rate of 90 N, and 60 P_2O_5 kg/ha. Half of the phosphorous and nitrogen was applied at planting and the remaining half was applied at first irrigation. Pak-81 wheat was seeded using a twelve row seed drill (SPSC/200-NARDI) at a seeding rate of 100 kg/ha in early November. The first irrigation was applied within 12-18 days of germination; the second irrigation was applied at flowering and the remaining irrigations were applied as needed with the total not exceeding 5 applications during the entire cropping season.

A germination test to determine the percentage of viable seeds and the required seeding rate was performed by using the Petri dish method. A germination test was carried out to avoid poor stand establishment due to the age of seed, weather damage, storage conditions, improper physical development, mechanical damage and other factors. To run the germination test, representative composite samples were obtained. Then three 150 seed sub-samples were placed evenly on moistened filter paper in each Petri dish. These dishes were placed in a warm place (20-30°C) for 4 to 5 days. At the end of the germination period, seeds having normal shoots and roots were counted; all shoots were required to be longer than 2 cm. The number of shoots counted and the number of seeds germinated in each sample are given in Table 3. Seed from the same lot was used at all three sites.

Prior to tillage (Figure 12), base-line data for bulk density, moisture content, penetration resistance and surface roughness were collected. The tillage treatment was then applied. A headland pattern with rounded corners was adopted for all operations except for the cultivator which used a circuitous pattern with turn strips at each end (RNAM, 1983). Following tillage, core samples, penetration resistance, surface roughness, soil moisture, and soil temperature data were gathered.

Undisturbed soil cores to a depth of 15 cm were taken in each plot before and after tillage. A core sampler (Figure 2) was driven into the soil with a hammer provided with the sampler. It was then pulled up and the soil sample was transferred to a plastic bag. Each bag was numbered for plot and treatment. The mass was determined before and after drying to constant weight at 105°C for 24 hours, and the volume of the samples as taken in the field was recorded. Seventy two soil cores were obtained from each site (12 plots x 2 locations within plot x 3 depths). Samples were used to

Table 3. Seed germination test

Subsamples	No. of seeds	No. germinated	% germinated
1	150	137	91.3
2	150	141	94.0
3	150	136	90.6

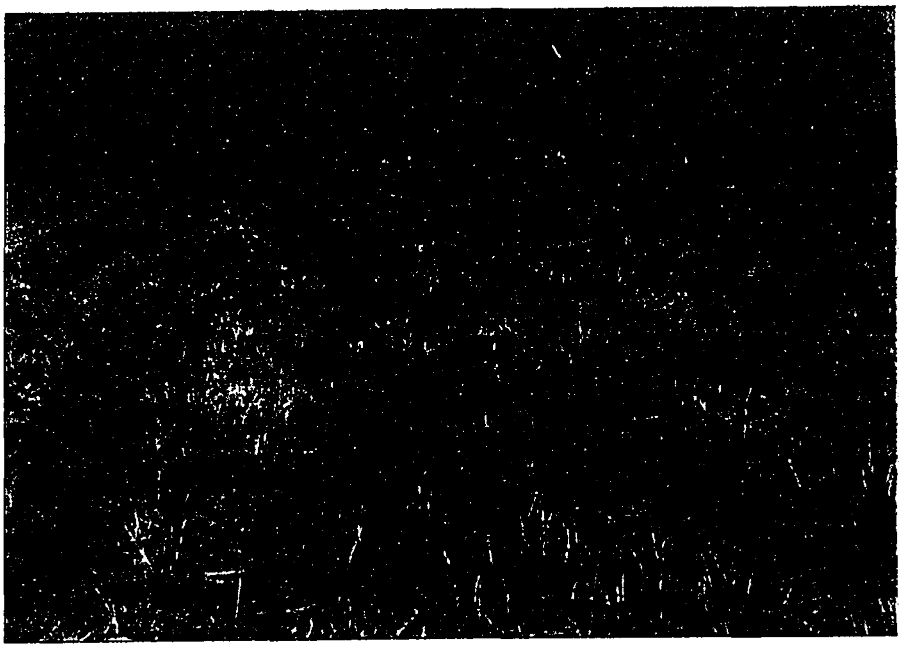

Figure 12. Experimental plot before tillage

determine soil bulk density and moisture content.

$$BD = W_{od} / V_t,$$

where BD = dry bulk density of soil, Mg/m^3

W_{od} = mass of oven dry soil, Mg.

V_t = total volume of undisturbed sample, m^3.

Soil water content was measured gravimetrically using the samples collected for bulk density measurements. The samples were placed in airtight bags and were carried to the laboratory for immediate weighing. The moisture content was computed using the following formula:

$$P_w = (W_w - W_{od})/W_{od} * 100,$$

where P_w = %moisture content on the dry weight basis.

W_w = mass of wet soil.

W_{od} = mass of oven dry soil.

Penetration resistance readings were recorded at approximately 5, 10, 15, 20, 25, and 30 cm depths before and after the tillage treatment.

Soil temperature readings were recorded at 5, 10, and 15 cm depth at two locations in individual plots. Readings were taken at the same location or in the same hole created by removal of the bulk density samples before and after tillage.

Tillage depth was measured using the depth meter (Figures 5 and 13). Following passage of the tractor and implement, readings were taken by putting the depth meter on the untilled

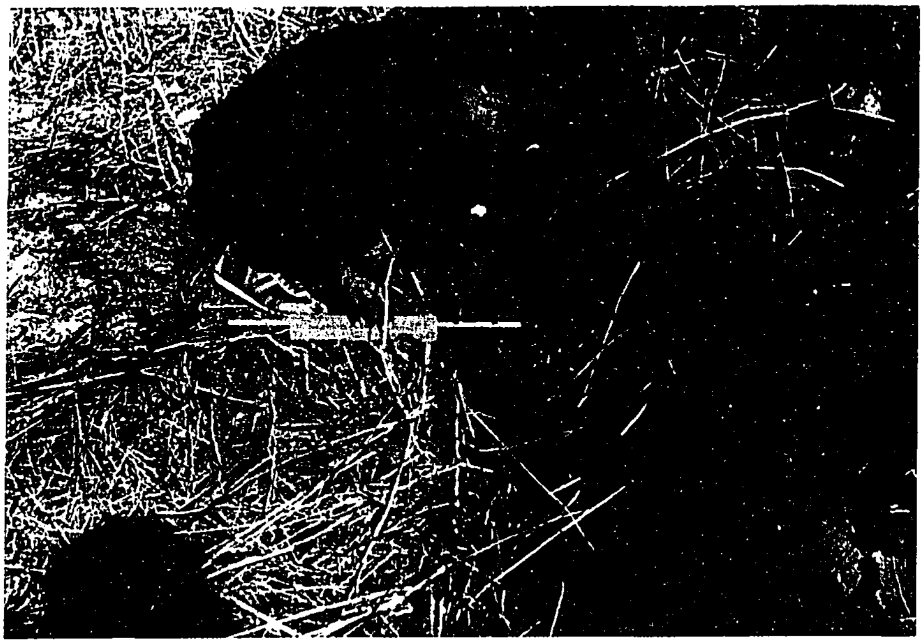

Figure 13. A close view of the depth meter in the field

surface and lowering the graduated pins into the tilled area after removing the soil to the depth of tillage.

Surface roughness data were collected before and after the treatments were applied. A profilometer was used for this purpose. The profilometer was placed on the surface, and after leveling its pins were lowered to the soil surface to give a representation of the surface profile. Pin height readings were recorded.

The mean weight diameter of aggregates was computed for each sample and was used as an index to express the distribution of aggregate size (van Bavel, 1949; Younker and McGuinness, 1956). Mean weight diameter was determined from the following equation:

$$MWD = \sum_{i=1}^{n} (x_i w_i)/W,$$

where MWD = mean weight diameter, (mm)

x_i = mean diameter of any particle size range of aggregates separated by sieving

w_i = mass of the aggregates in that range, (kg)

W = total mass of the sample analysed, kg.

Emergence counts were started 7 days after sowing, and were continued daily for the next 14 days. Locations for the emergence counts were pre-selected randomly after sowing.

Two methods were used to collect samples of wheat yields. Figure 14 shows a field ready for harvesting. First, yield samples from one square meter areas were randomly taken from the diagonal of each plot, and were then threshed by hand. Second, yield samples where collected by harvesting a 25 meter long by one meter wide strip across the whole treatment. Harvesting for this method was carried out by using a one meter wide ALMACO plot combine. Three 1 m^2 samples and one 25 m^2 sample from each plot were collected. Yields were then adjusted to 14% moisture content (RNAM, 1983).

Tillage effects on bulk density, penetration resistance, and moisture content were evaluated by an analysis of variance, with tillage treatment as the main effect and depth as the split-plot effect. Means comparison were made using Duncan's multiple range test (Steel and Torrie, 1980).

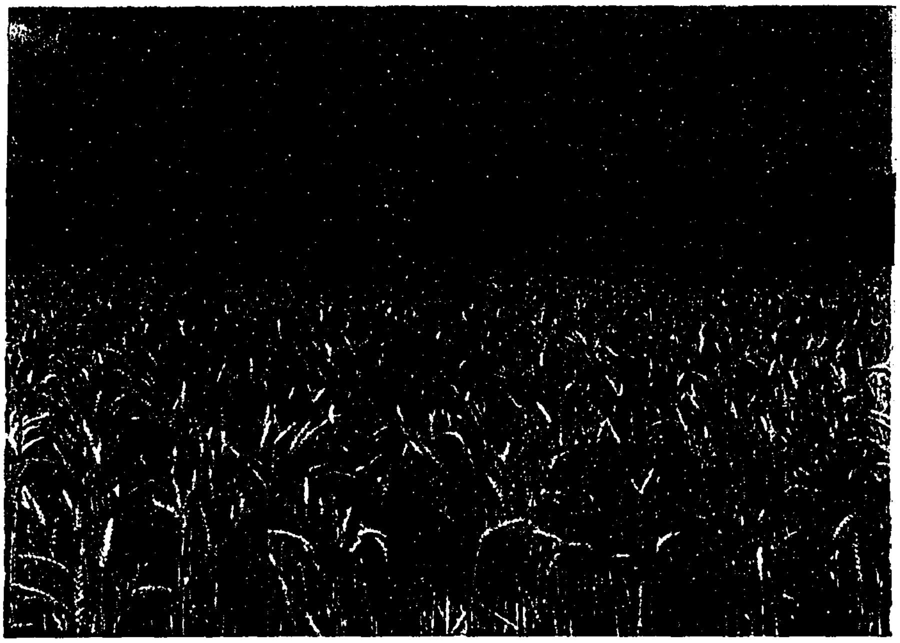

Figure 14. Experimental plot before harvesting

V. RESULTS AND DISCUSSION

A. Soil Physical Properties as Affected by Tillage

Data are given in Appendices A through G. The analysis of variance tables obtained using PROC GLM programs are presented at the end of each appendix. Tables of means, summary of significance levels for F-tests, and the graphical presentations are included in the text for discussion.

1. Bulk Density

Soil bulk density samples at two locations and at three depths in each plot, before and after the treatment were obtained. These bulk densities were calculated on a dry basis, and the data are presented in Tables 1, 2, and 3 in Appendix A. Data summaries are given in Tables 5 through 8. Summary of significance levels for F-tests is given in Table 4. Tillage treatments at all sites showed a significant effect on bulk density. Similarly, depth significantly affected bulk density at all three locations. Bulk density effects for treatment and depth interactions were non-significant before tillage treatment and remained non-significant after the treatment was applied except at Pirsabaq. This may be due to the fact that bulk density increased with depth (0-15 cm for this study) at all sites,

Table 4. Summary of significance levels for analysis of variance for the effect of tillage treatment and soil depth on bulk density at Islamabad (I), Faisalabad (F), and Pirsabaq (P)

	Significance levels for F-tests					
	Bulk density (Mg/m^3)					
	Before			After		
Effect	I	F	P	I	F	P
Tillage Trt.	0.01	ns	ns	0.0001	0.008	0.07
Depth	ns	ns	ns	0.0004	0.0001	0.0009
Tillage by depth[1]	ns	ns	0.06	ns	ns	0.09

ns = non significant at the 0.10 level.
[1]Sampling depth.

were also significant before treatment, which shows the existence of some variation among the plots before tillage treatment application.

Mean comparison of bulk density among the treatments for all locations is given in Table 5. Tillage treatments at all sites showed a significant effect on bulk density but the results were not consistent. At Islamabad and Faisalabad, the rotavator showed the lowest density (average across depths), while at Pirsabaq, cultivator was lowest. But the overall mean bulk density (average across depths and sites) for all sites was lowest for the rotavator followed by moldboard, cultivator, and disk. Contradictory results were also reported by other researchers on the effect of tillage treatments on soil bulk density (Gantzer and Blake, 1978; Bauer and Black, 1981; Tollner et al., 1984; and Blevins et al., 1977). Mean bulk density for the different tillage treatments was consistently higher in clay loam (Islamabad, Faisalabad) compared to sandy clay loam (Pirsabaq). The coefficient of variation ranged from 3-17% for individual treatments and between the Sites.

From Tables 6, 7, and 8, when percentage changes in bulk density were calculated, it was found that the rotavator produced highest bulk density change (35%), followed by moldboard (26%), then disk (17%), and cultivator (2%), in clay

Table 5. Mean values of soil bulk density as effected by tillage treatments at Islamabad, Faisalabad, and Pirsabaq

	Bulk density[1] (Mg/m^3)				
Tillage	Islamabad	Faisalabad	Pirsabaq	Means	CV** (%)
C	1.19[a]	1.00[a]	0.84[b]	1.01	3-17
R	0.81[d]	0.83[b]	0.86[ab]	0.83	4-15
D	1.04[b]	1.13[a]	0.90[ab]	1.02	3-14
M	0.87[c]	1.07[a]	0.93[a]	0.96	3-11

**Coefficient of variation.
[abcd]Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.
[1]Comparison done on treatments within site.
C=Cultivator
R=Rotavator
D=Disk Harrow
M=Moldboard Plow

Table 6. Mean values of soil bulk density before and after tillage treatments with depth variation at Islamabad

	Bulk density* (Mg/m^3)							
	Before				After			
Trt.[1]	5cm	10cm	15cm	Means	5cm	10cm	15cm	Means
C	1.23	1.22	1.19	1.21[a]	1.16	1.19	1.23	1.19[a]
R	1.20	1.22	1.27	1.23[a]	0.73	0.78	0.91	0.81[d]
D	1.25	1.25	1.24	1.24[a]	0.93	1.03	1.17	1.04[b]
M	1.19	1.15	1.18	1.17[b]	0.84	0.89	0.93	0.87[c]
Depth[2] means	1.22[a]	1.21[a]	1.22[a]	1.21	0.91[b]	0.97[b]	1.06[a]	0.98

*Each value represents 6 observations.
[abcd]Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.
[1]Vertical comparison among treatments for before and after tillage done separately.
[2]Horizontal comparison among depths for before and after tillage done separately.
C=Cultivator
R=Rotavator
D=Disk Harrow
M=Moldboard Plow

Table 7. Mean values of soil bulk density before and after tillage treatments with depth variation at Faisalabad

	Bulk density* (Mg/m^3)							
	Before				After			
Trt.[1]	5cm	10cm	15cm	Means	5cm	10cm	15cm	Means
C	1.26	1.34	1.35	1.32[a]	0.89	0.98	1.12	1.00[a]
R	1.31	1.35	1.30	1.32[a]	0.78	0.86	0.84	0.83[b]
D	1.29	1.33	1.29	1.30[a]	1.02	1.13	1.24	1.13[a]
M	1.32	1.33	1.35	1.33[a]	1.01	1.11	1.11	1.07[a]
Depth[2] means	1.29[a]	1.34[a]	1.32[a]	1.32	0.92[c]	1.02[b]	1.08[a]	1.01

*Each value represents 6 observations.
[abc]Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.
[1]Vertical comparison among treatments for before and after tillage done separately.
[2]Horizontal comparison among depths for before and after tillage done separately.
C=Cultivator
R=Rotavator
D=Disk Harrow
M=Moldboard Plow

Table 8. Mean values of soil bulk density before and after tillage treatments with depth variation at Pirsabaq

	Bulk density* (Mg/m^3)							
	Before				After			
Trt.[1]	5cm	10cm	15cm	Means	5cm	10cm	15cm	Means
C	1.17	1.21	1.19	1.19[a]	0.69	0.86	0.95	0.84[b]
R	1.24	1.18	1.20	1.21[a]	0.83	0.88	0.86	0.86[ab]
D	1.16	1.19	1.26	1.21[a]	0.85	0.93	0.93	0.90[ab]
M	1.19	1.21	1.20	1.20[a]	0.89	0.95	0.96	0.93[a]
Depth[2] means	1.19[a]	1.20[a]	1.21[a]	1.20	0.81[b]	0.90[a]	0.92[a]	0.88

*Each value represents 6 observations.
[ab]Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.
[1]Vertical comparison among treatments for before and after tillage done separately.
[2]Horizontal comparison among depths for before and after tillage done separately.
C=Cultivator
R=Rotavator
D=Disk Harrow
M=Moldboard Plow

loam soil. At Faisalabad (Table 7), also a clay loam soil, percentage change in bulk density were rotavator (38%) > moldboard (20%) > cultivator (14%) > Disk (13%). At Pirsabaq (sandy clay loam) changes in bulk density were rotavator (30%), cultivator (30%), disk 26% (about double the percentage change for disk at Islamabad and Faisalabad), and moldboard (22%). The overall mean percentage changes in bulk density for all sites (average across depths and treatments), show rotavator (34%) produced a higher bulk density change than moldboard (23%). The cultivator and disk changes were the same (19%). However, sandy clay loam showed 6% greater change in bulk density than the clay loam in all treatments.

The main effect of depth (average across treatments) was highly significant on bulk density at each location after tillage. Figures 15, 16, and 17 show the bulk density before and after tillage at each depth (0-5, 5-10, and 10-15 cm) of the soil profile. These graphs show that the bulk density was reduced by tillage. The effect was greater for the 0-5 cm layer, except for cultivator at Islamabad.

Comparisons of mean bulk density values for the depth variations determined by the core method indicate that After:Before ratios ranged from 0.68 to 0.74 (26 to 32% change) in the 0 to 5 cm soil profile, from 0.75 to 0.80 (20 to 25% change) in the 5 to 10 cm soil profile, and from 0.76

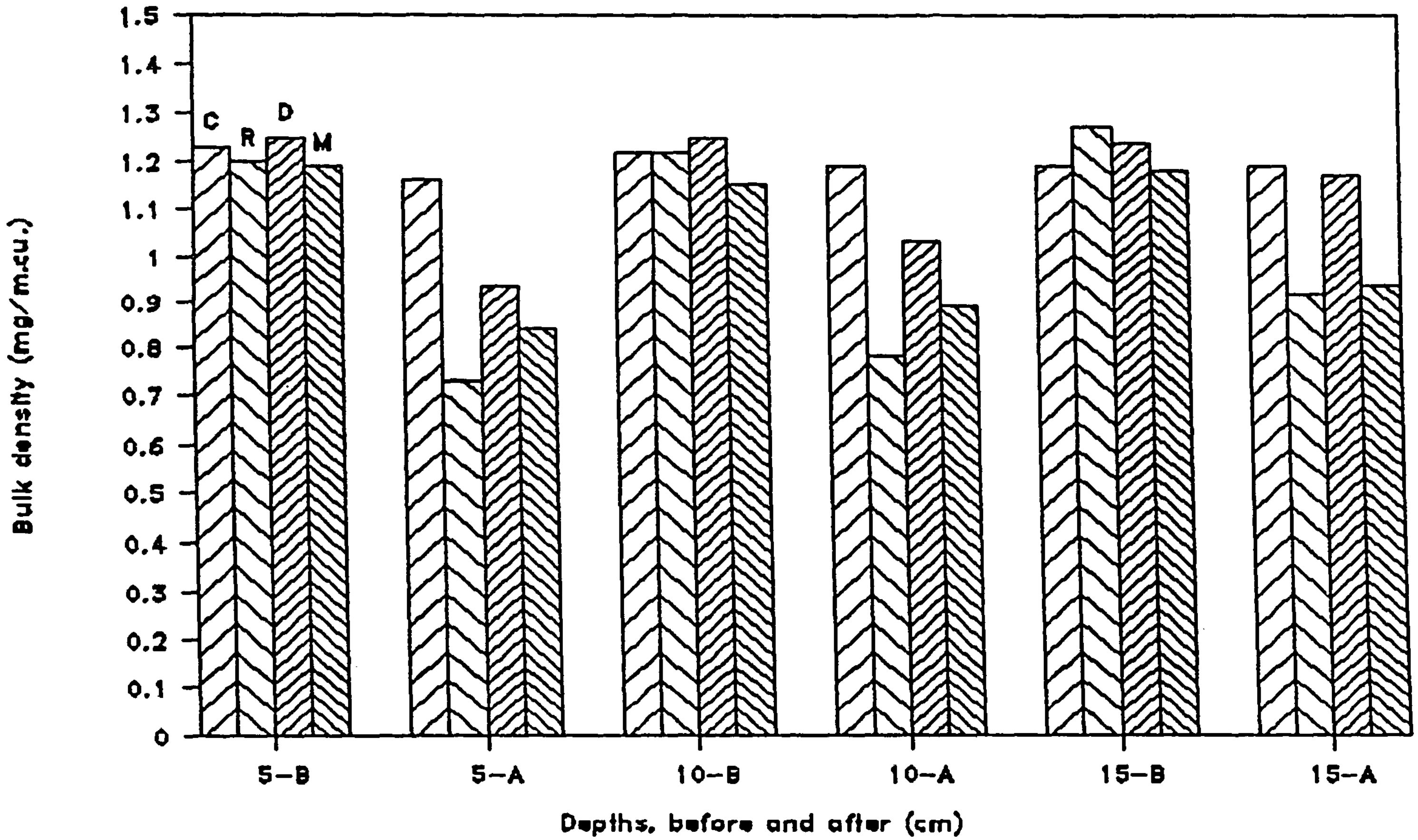

Figure 15. Mean bulk density for before and after tillage and depth at Islamabad

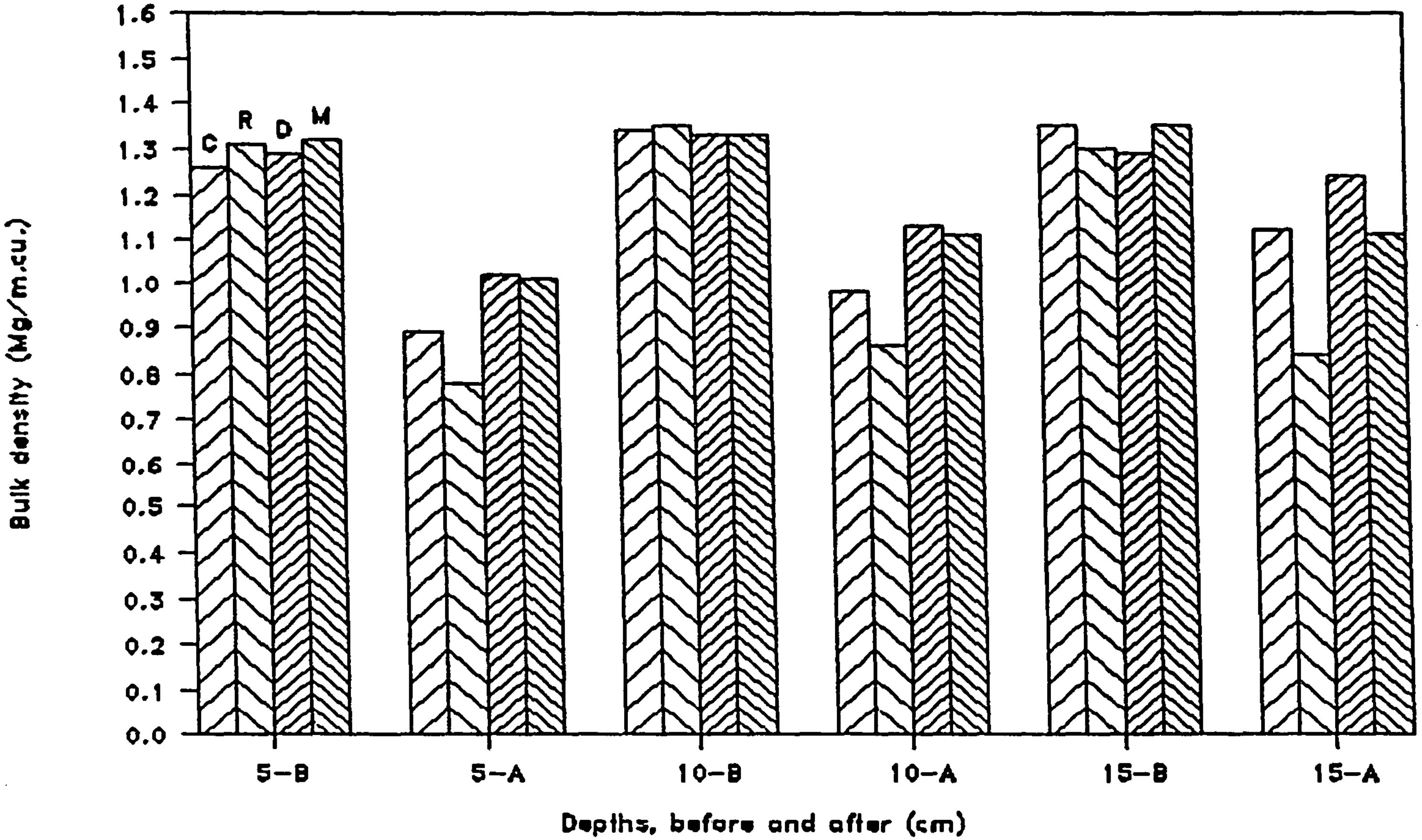

Figure 16. Mean bulk density for before and after tillage and depth at Faisalabad

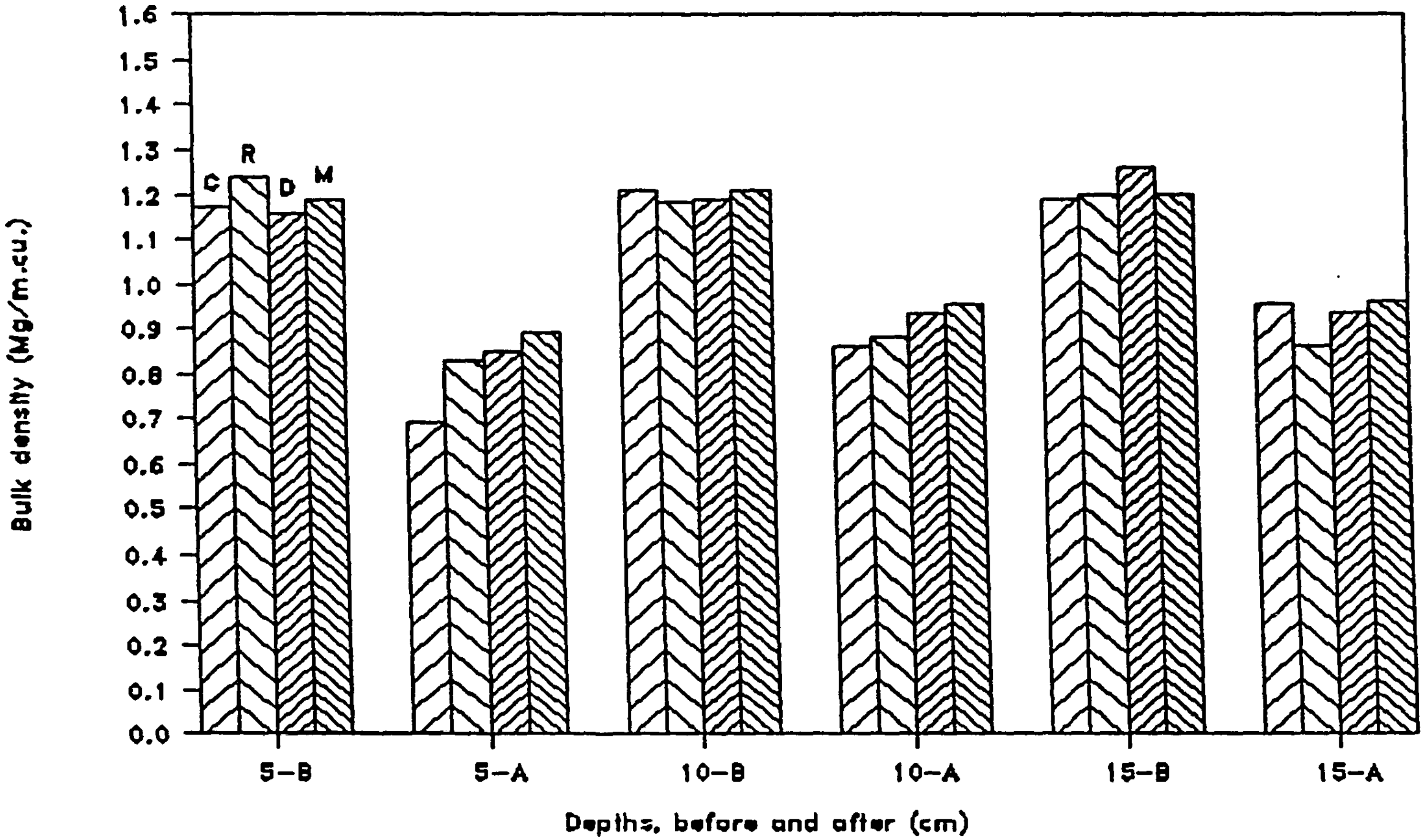

Figure 17. **Mean bulk density for before and after tillage and depth at Pirsabaq**

to 0.87 (13 to 24% change) in the 10 to 15 cm soil profile. Consistently higher values of percentage decrease in bulk density were obtained for 0 to 5 cm, followed by 5 to 10 cm and 10 to 15 cm, at all three locations. Pirsabaq (sandy clay loam) still showed higher changes (27%) compared to Islamabad and Faisalabad (clay loam) which had 19 and 24% changes respectively for the means across the depths.

2. Moisture Content

The gravimetric soil moisture content data were recorded at Islamabad, Faisalabad, and Pirsabaq following the tillage operations. The data are shown in Tables 1, 2, and 3 in Appendix B and the mean values are summarized in Tables 10, 11, 12 and 13. Summary of significance levels for F-tests is given in Table 9.

No statistical differences (Table 10) between the moisture contents due to tillage (average across depths) were found in the humid (Islamabad) and sub-humid (Pirsabaq) regions. The arid site (Pirsabaq) showed an effect on moisture content with tillage and depth, but the same differences existed before the tillage treatment. Therefore, this could have been caused by the pre-existing soil moisture gradient within the site. The maximum moisture difference between any two tillage and depth means within sites was less

Table 9. Summary of significance levels for analysis of variance for the effect of tillage treatment and soil depth on moisture content at Islamabad (I), Faisalabad (F), and Pirsabaq (P)

	Significance levels for F-tests					
	Before			After		
Effect	I	F	P	I	F	P
Treatments	0.0005	0.002	ns	ns	0.04	ns
Depth	ns	0.03	ns	ns	0.06	ns
Trt. by Depth*	ns	ns	ns	0.07	0.10	0.03

ns = non significant at the 0.10 level.
*Sampling depth.

Table 10. Mean comparison of moisture content for the tillage treatments soils at Islamabad, Faisalabad, and Pirsabaq

	Moisture content (%)						
Site	Tillage treatments*				Depth** (cm)		
	C	R	D	M	5	10	15
Islamabad	20.7	20.0	19.6	20.7	20.1	20.3	20.2
Faisalabad	15.1[b]	17.1[a]	16.3[ab]	15.9[ab]	15.3[b]	16.9[a]	16.2[ab]
Pirsabaq	16.4	17.1	15.9	13.3	16.1	15.3	15.7

*Each value represents 18 observations.
**Each value represents 24 observations.
[ab]Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.
C=Cultivator
R=Rotavator
D=Disk Harrow
M=Moldboard Plow

than 4% (Tables 11, 12, and 13). Differences of this magnitude will not be expected to usually cause variations in plant growth. This similarity in moisture can be attributed to the irrigation provided before the tillage treatments to bring the soil to field capacity for cultivation. The similarity in moisture between different tillage systems for before and after tillage values was also reported by Luttrell et al., (1964) and Elamin et al., (1983).

The depth variation (average across treatments) for moisture retention did not show any significant trend for all three sites. Mean values reflected higher values (average across depths and treatments) of moisture content for a humid region (Islamabad, 20%) compared to the semi-arid (Faisalabad, 16%) and sub-humid (Pirsabaq, 16%) locations (Table 10).

3. <u>Penetration Resistance</u>

Soil penetration resistance measurements were taken close to the holes where bulk density samples were collected. These data are listed in Tables 1, 2, and 3 in Appendix C.

Summarized data are given in Tables 15, 16, 17 and 18. Summary of significance levels for F-tests is presented in Table 14. Graphical representations of the treatment effects are shown in Figures 18 through 23. Penetration resistance values for tillage, depth and their interactions, all showed

Table 11. Mean comparison of moisture content for before and after tillage treatments with depth variation at Islamabad

	Moisture Content (%)							
	Before				After			
Trt.[1]	5cm	10cm	15cm	Means	5cm	10cm	15cm	Means
C	19.7	21.3	21.5	20.8[b]	19.7	22.3	20.0	20.7[a]
R	22.6	19.0	18.7	20.1[b]	20.3	19.2	20.4	20.0[a]
D	17.8	19.1	20.4	19.1[b]	19.8	19.5	19.4	19.6[a]
M	25.1	27.3	25.2	25.9[a]	20.7	20.4	21.0	20.7[a]
Depth[2] means	21.3[a]	21.7[a]	21.4[a]	21.5	20.1[a]	20.3[a]	20.2[a]	20.2

*Each value represents 6 observations.
[ab]Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.
[1]Vertical comparison among treatments for before and after tillage done separately.
[2]Horizontal comparison among depths for before and after tillage done separately.
C=Cultivator
R=Rotavator
D=Disk Harrow
M=Moldboard Plow

Table 12. Mean comparison of moisture content for before and after tillage treatments with depth variation at Faisalabad

	Moisture Content (%)							
	Before				After			
Trt.[1]	5cm	10cm	15cm	Means	5cm	10cm	15cm	Means
C	13.8	14.5	14.6	14.3[b]	12.0	16.0	17.0	15.1[a]
R	12.6	14.4	14.8	13.9[b]	18.0	17.4	15.9	17.1[a]
D	15.2	16.4	17.0	16.2[a]	15.1	18.1	15.8	16.3[a]
M	15.1	16.5	16.3	16.0[a]	15.6	16.3	16.0	15.9[a]
Depth[2] means	14.2[b]	15.4[a]	15.7[a]		15.3[a]	16.9[a]	16.2[a]	

[*]Each value represents 6 observations.
[ab]values of levels of each factor followed by different letters are statistically different at 90 percent probability level.
[1]Vertical comparison among treatments for before and after tillage done separately.
[2]Horizontal comparison among depths for before and after tillage done separately.
C=Cultivator
R=Rotavator
D=Disk Harrow
M=Moldboard Plow

Table 13. Mean comparison of moisture content for before and after tillage treatments with depth variation at Pirsabaq

	Moisture Content (%)							
	Before				After			
Trt.[1]	5cm	10cm	15cm	Means	5cm	10cm	15cm	Means
C	17.6	17.0	19.3	17.9[a]	15.4	16.4	17.4	16.4[a]
R	18.6	15.9	16.6	17.0[a]	18.2	16.5	16.7	17.1[a]
D	18.1	17.7	16.0	17.3[a]	15.8	15.8	16.0	15.9[a]
M	17.8	17.8	18.2	17.9[a]	15.1	12.2	12.5	13.3[b]
Depth[2] means	18.0[a]	17.1[a]	17.5[a]		16.1[a]	15.3[a]	15.7[a]	

[*]Each value represents 6 observations.
[ab]Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.
[1]Vertical comparison among treatments for before and after tillage done separately.
[2]Horizontal comparison among depths for before and after tillage done separately.
C=Cultivator
R=Rotavator
D=Disk Harrow
M=Moldboard Plow

highly significant effects (Table 14). Depth shows significantly different values for the penetration resistance even before the tillage treatment was applied (Table 16 through 18). This is in agreement with previous investigations (Blake et al., 1976; Dechnik et al., 1982; McKyes et al., 1979; Negi et al., 1981; Soane et al., 1982; and Sial, 1987). All treatments (average across depths) had a highly significant effect on penetration resistance (Table 15), but similar to bulk density the results were not consistent. For instance, cultivator and disk treatments showed higher cone indexes at Islamabad, disk showed highest at Faisalabad, and rotavator showed highest at Pirsabaq. But moldboard plowing reduced cone index at all sites. Because there was no difference in moisture between treatment means, low bulk density caused by the moldboard is assumed to be the reason for these differences in soil strength. Other tillage treatments did not loosen the soil as much as did the moldboard.

Soil strength increased with increasing soil depth consistently at all three sites. The upper two depths (0-5, 5-10 cm) and lower two (20-25, 25-30 cm) were not significantly different, but major differences were observed from 10 to 20 cm depth.

Table 14. Summary of significance levels for ANOVA for the effect of tillage treatment and soil depth on penetration resistance at Islamabad (I), Faisalabad (F), and Pirsabaq (P)

	Significance levels for F-test					
	Before			After		
Effect	I	F	P	I	F	P
Treatments	ns	ns	ns	0.0006	0.01	0.003
Depth	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Trt. by Depth*	0.04	ns	ns	0.0008	0.0001	0.0003

*Sampling depth.
ns=Non-significant at the 0.10 level.

Table 15. Effect of tillage and depth on mean soil penetration resistance after tillage

Factor	Level	N	Islamabad	Faisalabad	Pirsabaq
			kPa		
Tillage					
	Cultivator	54	1690[a]	2050[ab]	1850[b]
	Rotavator	54	860[b]	1510[b]	2720[a]
	Disk Harrow	54	1690[a]	2610[a]	2030[b]
	Moldboard	54	600[b]	1280[b]	1150[c]
Sampling Depth					
	0-5 cm	36	70[e]	110[d]	0[d]
	5-10 cm	36	380[d]	520[d]	10[d]
	10-15 cm	36	1100[c]	1350[c]	700[c]
	15-20 cm	36	1640[b]	2520[b]	2560[b]
	20-25 cm	36	2030[a]	3430[a]	4130[a]
	25-30 cm	36	2040[a]	3260[a]	4240[a]

[abcde]Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.
*Vertical comparison were done among the means.

Table 16. Mean soil penetration resistance values at Islamabad, before and after tillage application

Tillage	Penetration resistance (kPa)						
	Depth (cm)						
	0-5	5-10	10-15	15-20	20-25	25-30	Means*
	Before Tillage						
Cult.	1330	1840	2000	2240	2270	2240	1991[a]
Rotavator	1220	1920	2170	1460	1580	1610	1665[a]
Disk	1120	1860	1910	2050	1970	1970	1819[a]
MBoard	1170	1430	1450	1510	1670	1720	1496[a]
Depth Means**	1210[b]	1760[a]	1880[a]	1810[a]	1880[a]	1880[a]	1743
	After Tillage						
Cult.	150	480	1560	2500	2750	2710	1695[a]
Rotavator	0	20	110	1360	1900	1780	864[b]
Disk	110	950	2160	2150	2410	2370	1697[a]
MBoard	110	90	570	550	1080	1310	606[b]
Depth Means**	70[e]	380[d]	1100[c]	1640[b]	2030[a]	2040[a]	1216

[abcde]Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.

*Vertical comparison were done among the tillage means.

**Horizontal comparison were done among the depth means.

Table 17. Mean soil penetration resistance values at Faisalabad, before and after tillage application

Tillage	Penetration resistance (kPa) Depth (cm) 0-5	5-10	10-15	15-20	20-25	25-30	Means*
	Before Tillage						
Cult.	2030	2350	2910	3580	3220	2470	2764[a]
Rotavator	1710	1960	2370	3080	3030	2650	2471[a]
Disk	1510	1830	2900	3540	3510	2600	2649[a]
MBoard	1630	1630	2820	3500	3170	2560	2555[a]
Depth Means**	1720[c]	1940[c]	2070[b]	3430[a]	3230[a]	2570[b]	2610
	After Tillage						
Cult.	0	180	1730	3340	3420	3620	2052[ab]
Rotavator	0	0	40	1650	4060	3310	1513[b]
Disk	400	1280	2870	3960	3660	3510	2619[a]
MBoard	70	610	760	1110	2550	2610	1287[b]
Depth Means**	110[d]	520[d]	1350[c]	2520[b]	3430[a]	3260[a]	1867

[abcde]Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.
*Vertical comparison were done among the tillage means.
**Horizontal comparison were done among the depth means.

Table 18. Mean soil penetration resistance values at Pirsabaq, before and after tillage application

Tillage	Penetration resistance (kPa) Depth (cm)						
	0-5	5-10	10-15	15-20	20-25	25-30	Means*
	Before Tillage						
Cult.	1570	3410	4600	5020	4970	4570	4026^{a}
Rotavator	1670	2900	4180	4510	4550	4170	3668^{a}
Disk	1090	2330	4290	4550	4310	4190	3465^{a}
MBoard	1140	2400	3830	4150	4190	3450	3195^{a}
Depth Means**	1370^{d}	2760^{c}	4220^{ab}	4530^{a}	4510^{ab}	4090^{b}	3588
	After Tillage						
Cult.	0	0	520	2170	4260	4180	1859^{b}
Rotavator	0	40	130	4300	5600	5110	2728^{a}
Disk	0	0	740	3200	4120	4150	2036^{b}
MBoard	0	0	240	600	2550	3520	1153^{c}
Depth Means**	0^{d}	10^{d}	700^{c}	2560^{b}	4130^{a}	4240^{a}	1944

abcdeValues of levels of each factor followed by different letters are statistically different at 90 percent probability level.
*Vertical comparison were done among the tillage means.
**Horizontal comparison were done among the depth means.

Cone Index trends were similar at all sites. Highest values of penetration resistance before tillage were found at Pirsabaq (Table 18), followed by Faisalabad (Table 17) and Islamabad (Table 16). Figures 18 through 23 show the penetration resistance values before and after tillage for each depth at all locations. They show the drastic reduction of penetration resistance after tillage in the 0-15 cm soil profile. Zero penetration resistance refers to the condition where the dial gauge failed to detect the penetration force exerted by the instrument itself, due to its weight.

Percentage decrease in penetration resistance due to tillage was higher at Pirsabaq (sandy clay loam) than at the other two sites. It was found that moldboard plowing produced greater change in penetration resistance (50-60%) followed by rotavator (38-48%), then cultivator (15-26%), and disk (1-6%) treatments. At Islamabad and Faisalabad, the change in penetration resistance with tillage treatment followed the same trend M > R > C > D. But at Pirsabaq M > C > D > R, the change due to rotavator was lowest. The percentage decrease in penetration resistance for sandy clay loam was 16% greater than for the clay loam.

Figures 19, 21, and 23 show the decrease in penetration resistance values after the tillage application. The greatest decrease was observed for moldboard at all sites. Rotavator

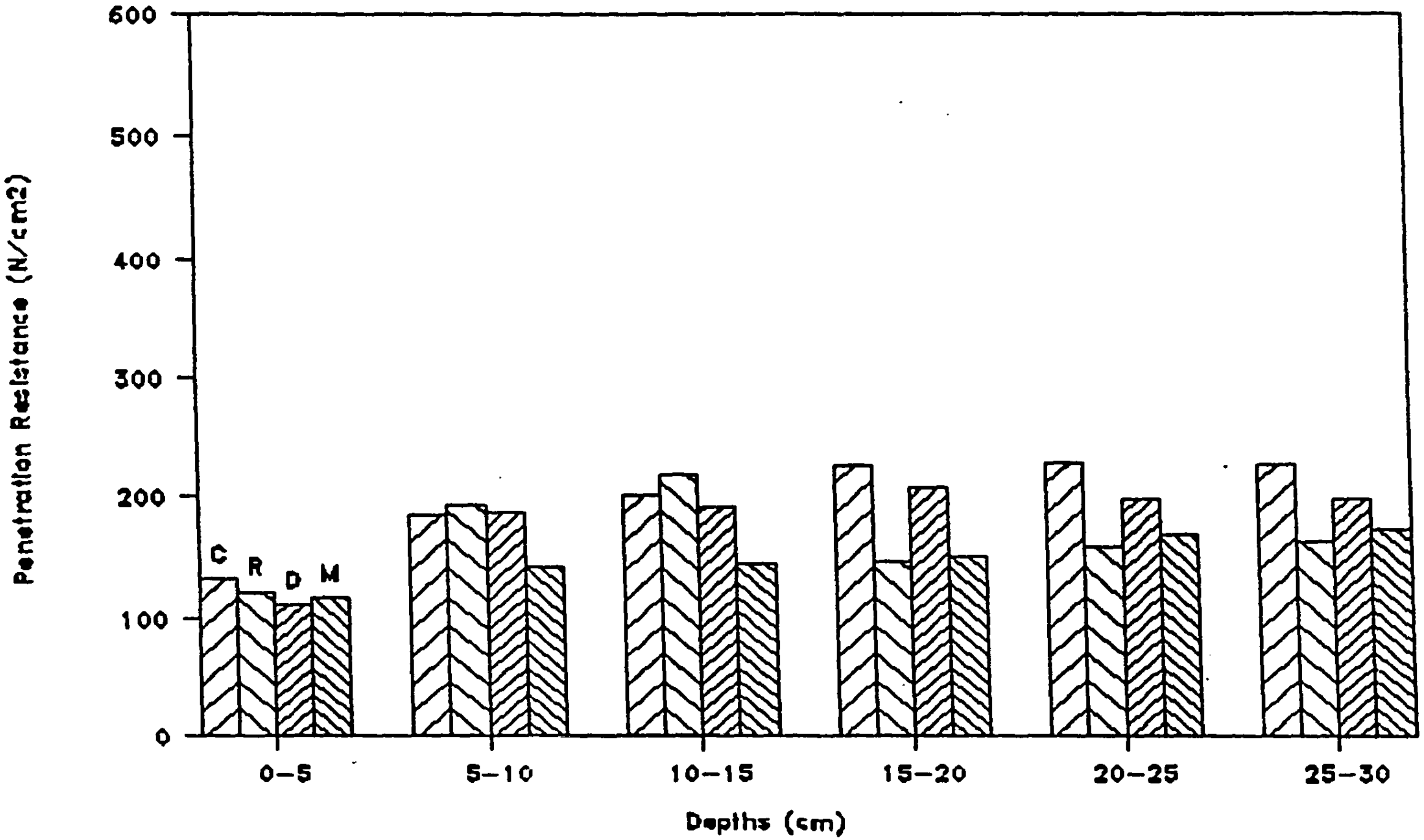

Figure 18. Mean penetration resistance before tillage and depth at Islamabad

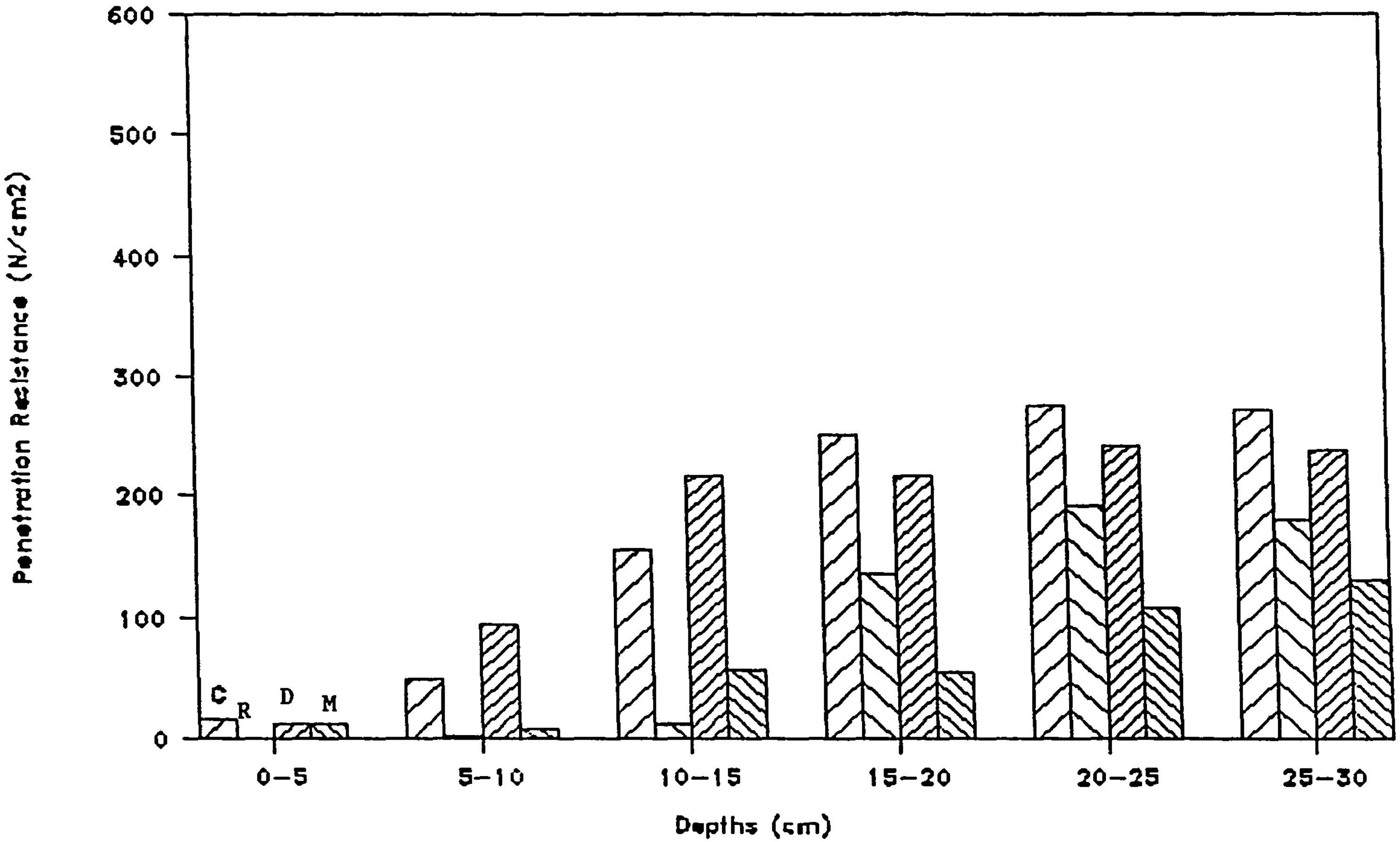

Figure 19. Mean penetration resistance after tillage and depth at Islamabad

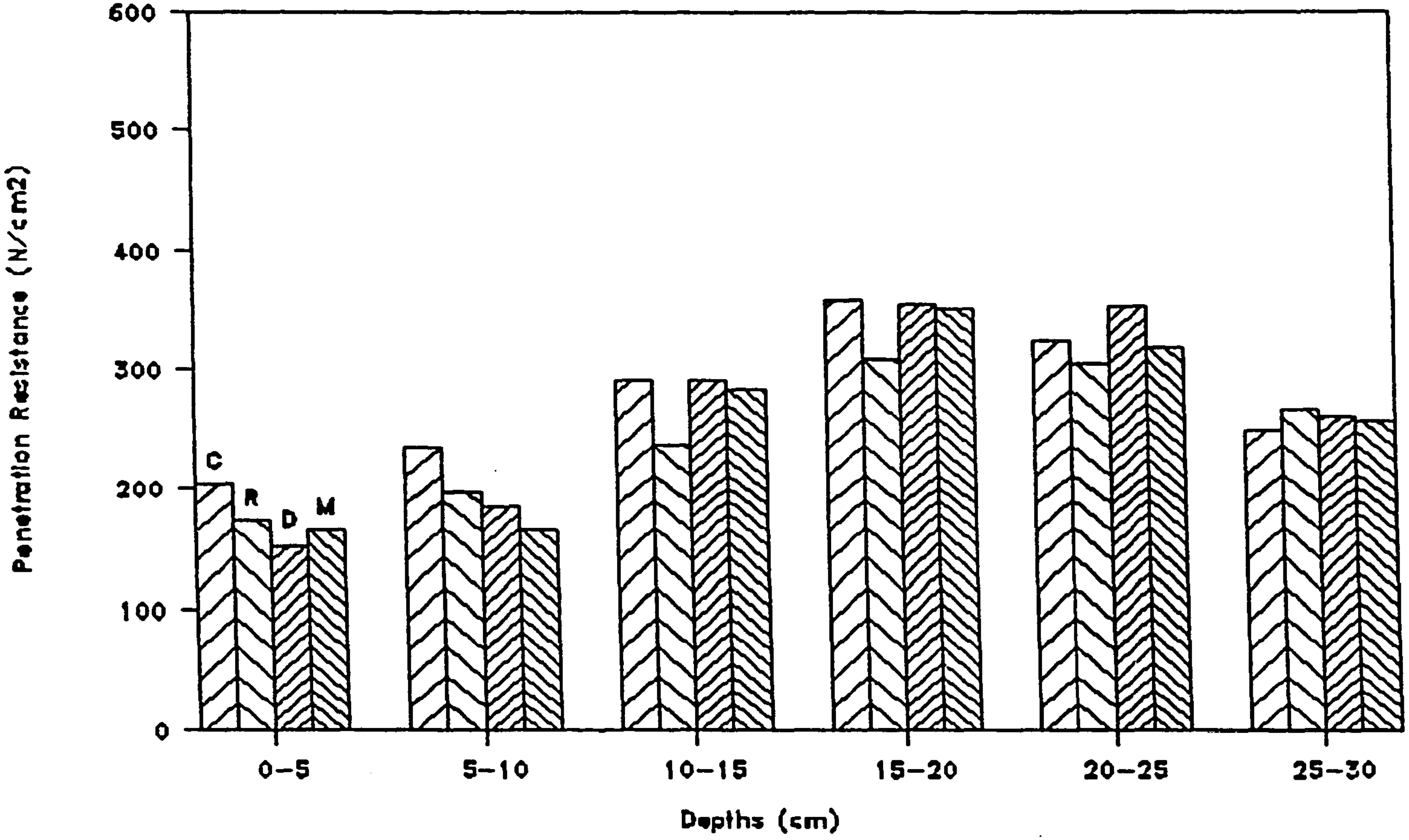

Figure 20. Mean penetration resistance before tillage and depth at Faisalabad

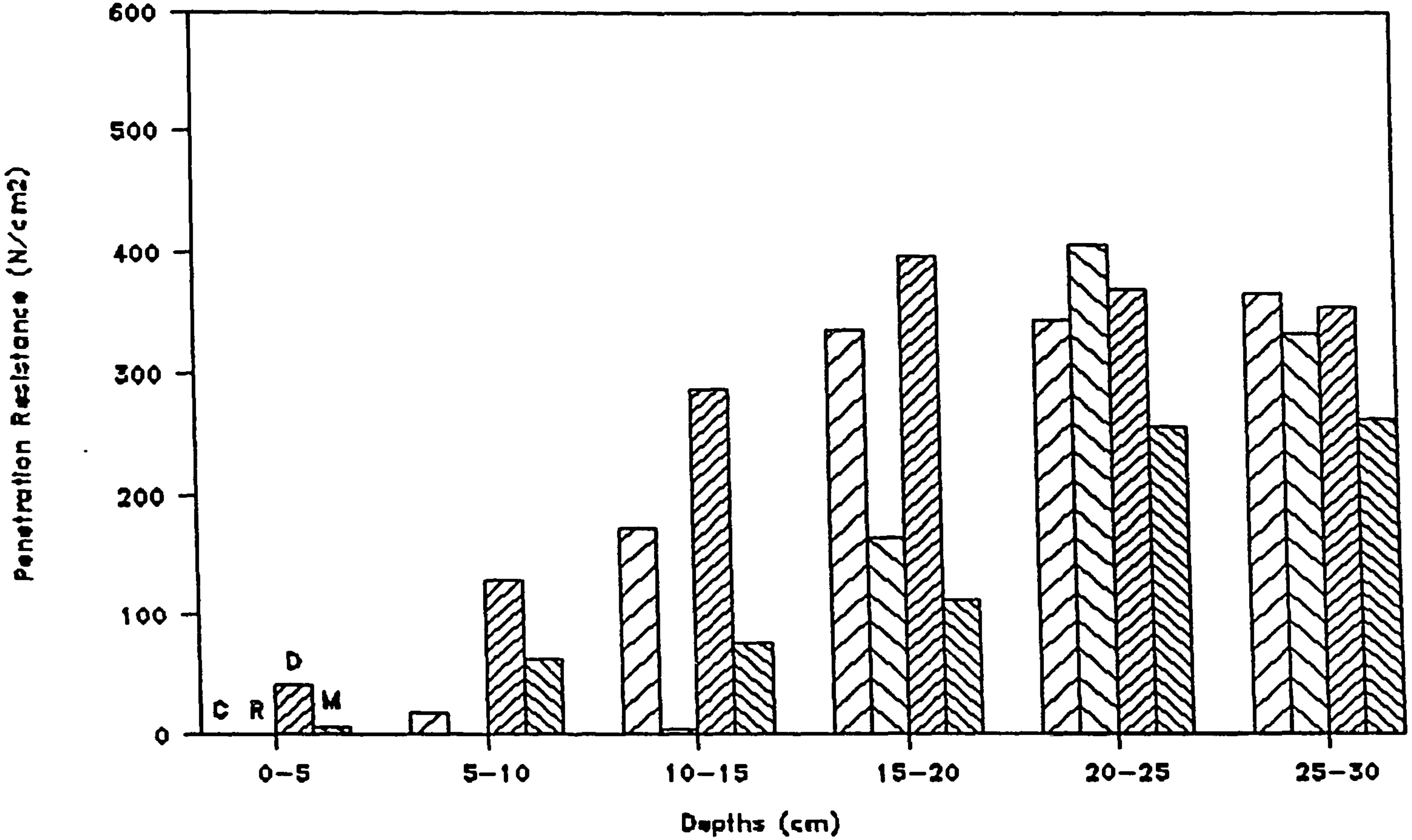

Figure 21. Mean penetration resistance after tillage and depth at Faisalabad

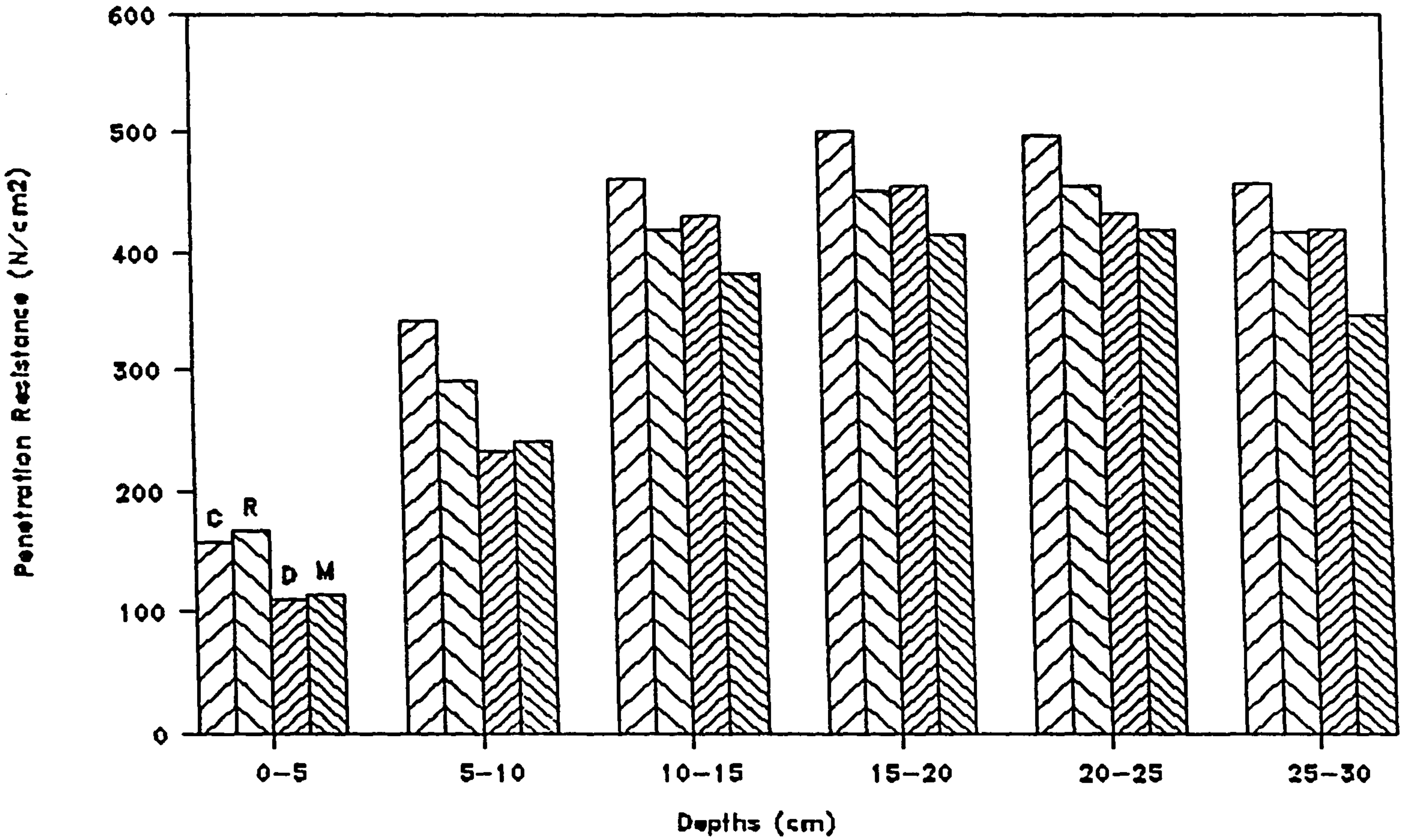

Figure 22. Mean penetration resistance before tillage and depth at Pirsabaq

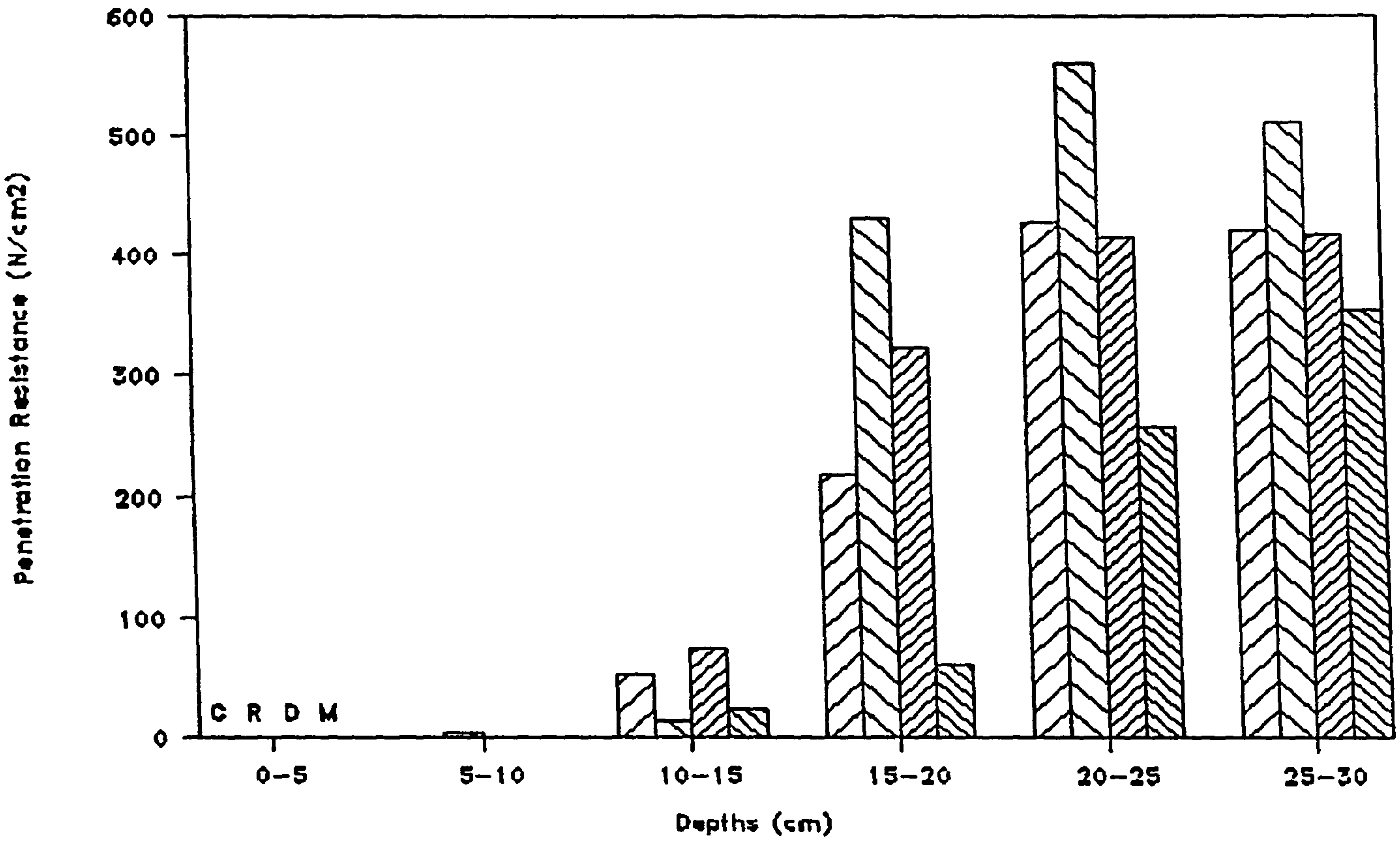

Figure 23. **Mean penetration resistance after tillage and depth at Pirsabaq**

showed the second lowest decrease for Islamabad and Faisalabad (Table 16 and 17), but at Pirsabaq (Table 18) disking had the lowest decrease.

The penetration resistance values before tillage ranged from 1090 to 5050 kPa (highest and lowest both observed at Pirsabaq) and the range after tillage was 0 to 1280 kPa in the 0-10 cm layer, 40-4300 kPa in 10-20 cm and 1080 to 5600 kPa in 20-30 cm soil profile. These changes were clearly related to the depth of tillage in each treatment. The rotavator, which tilled to 12 cm depth, showed changes in all sites throughout the 0-15 cm soil profile (Table 16, 17, and 18). Disking depth was measured to 9 cm, and changes in penetration resistance were noted through the 0-10 cm profile. Cultivator depth was 12 cm, and changes were noted in 10-15 cm soil profile. Moldboard depth was 22 cm, and changes in penetration resistance in the 15-20 cm soil profile were measured. Penetration resistance in the soil profile immediately beneath working depth of individual tillage had no consistent trend; in some instances values are higher and at others lower than the before tillage. At deeper depths, penetration resistance was consistently greater than before tillage (Figures 19, 21, and 23), perhaps indicating the influence of traffic (tractor and implement) on penetration resistance. This trend was consistent at all sites. This is in agreement with Rizvi, (1987); Sial, (1987); McKyes et al., (1977); Negi et al., (1981) and Soane et al., (1982). Bauder et al. (1981) reported an increase in penetrometer cone index values at the 10 cm depth compared with strength above and below this depth, which could be interpreted as a traffic and/or tillage-induced pan. Greatest differences in penetration resistance before and after tillage occurred near the soil surface in the tilled layer (0-15 cm). The differences narrowed at greater depths.

Comparisons of mean penetration resistance values for the depth variation determined by using the cone penetrometer indicate that the After:Before ratio ranged from 0-0.06 (94 to 100%) in the 0 to 5 cm, 0-0.26 (73 to 100%) in the 5 to 10 cm, 0.16-0.59 (35 to 83%) in the 10 to 15 cm, 0.56-0.91 (9 to 43%) in the 15 to 20 cm, 0.91-1.08 (-8 to 8%) in the 25 to 30 cm, and 1.04-1.27 (-4 to -27%) in the 25-30 cm soil profile. A negative value shows an increase in resistance after tillage. Consistently higher values of percentage decrease in resistance were obtained with increasing depth. The sandy-clay-loam soil had greater changes (55%) than the clay loam, where the overall changes across treatments and depths were 34% and 32% at Islamabad and Faisalabad respectively.

The depth by treatment interaction was also highly significant. The effect of depth on penetration resistance, comparing all three data sets showed consistent results. The coefficient of variation among the treatment combination at the three sites ranged from 4.64 to 5.10, and 11.31 to 18.79 for before and after tillage respectively.

4. Soil Temperature

Soil temperature data are shown in Tables 1 through Table 6 in Appendix D, and the summarized data are shown in Tables 20 through 22. Summary of the significance levels for F-tests is given in Table 19. Statistical analysis showed significant differences in temperature with treatment and with depth variations after the tillage. Significant, but not consistent values were also observed for before tillage (Table 19). These results were confusing to interpret. Tables 20, 21, and 22 show that the highest values at all sites were observed for rotavator, followed by moldboard. At the humid site (Islamabad), rotavator was higher, followed by moldboard and the lowest was for cultivator and disk. At the sub-humid and semi-arid sites soil temperature in the rotavator treatment was highest, followed by moldboard. Temperature in the cultivator plots behaved differently at the two sites. Moldboard and disk treatments showed highest temperature at semi-arid and lowest temperature at sub-humid. Depth by treatment interaction was significant before treatment but not after treatment. This simply means that temperature variations with depth were not consistent in the plots prior

Table 19. Summary of significance levels for ANOVA for the effect of tillage treatment and soil depth on Soil Temperature at Islamabad (I), Faisalabad (F) and Pirsabaq (P)

	Significance levels for F-test					
	Before			After		
Effect	I	F	P	I	F	P
Treatments	0.01	0.0001	0.0001	0.0002	0.0001	0.0001
Depth	0.0001	ns	0.0001	0.0001	0.0002	0.0001
Trt. by Depth*	0.06	0.0006	0.04	ns	ns	ns

*Sampling depth.
ns= Non-significant at the 0.10 level.

Table 20. Mean comparison of soil temperature for before and after tillage treatments with depth variation at Islamabad

	Before				After			
	---------- °C ----------							
Trt.[1]	5cm	10cm	15cm	Means	5cm	10cm	15cm	Means
C	20.2*	18.2	17.2	18.5[ab]	18.8	18.0	17.7	18.2[c]
R	21.5	19.8	18.8	20.0[a]	21.3	21.0	20.5	20.9[a]
D	20.0	19.2	18.7	19.3[ab]	18.7	16.7	16.8	17.4[c]
M	17.8	17.0	16.8	17.2[b]	20.0	19.0	19.0	19.3[b]
Depth[2] means	19.9[a]	18.5[b]	17.8[c]		19.7[a]	18.7[b]	18.5[b]	

*Each Value represents 6 observations.
[abc]Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.
[1]Vertical comparison among treatments for before and after tillage done separately.
[2]Horizontal comparison among depths for before and after tillage done separately.
C=Cultivator
R=Rotavator
D=Disk Harrow
M=Moldboard Plow

Table 21. Mean comparison of soil temperature for before and after tillage treatments with depth variation at Faisalabad

	Soil Temperature* (°C)							
	Before				After			
Trt.[1]	5cm	10cm	15cm	Means	5cm	10cm	15cm	Means
C	18.0	18.2	18.3	18.2[b]	22.7	22.3	21.3	22.1[a]
R	18.5	18.3	18.5	18.4[b]	22.8	23.2	22.2	22.7[a]
D	16.8	17.0	17.8	17.2[c]	19.2	19.3	18.3	18.9[b]
M	23.5	24.0	22.2	23.2[a]	19.0	19.3	18.3	18.9[b]
Depth[2] means	19.2[a]	19.4[a]	19.2[a]		20.9[a]	21.0[a]	20.0[b]	

*Each value represents 6 observations.
[abc]Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.
[1]Vertical comparison among treatments for before and after tillage done separately.
[2]Horizontal comparison among depths for before and after tillage done separately.
C=Cultivator
R=Rotavator
D=Disk Harrow
M=Moldboard Plow

Table 22. Mean comparison of soil temperature for before and after tillage treatments with depth variation at Pirsabaq

	Soil Temperature* (°C)							
	Before				After			
Trt.[1]	5cm	10cm	15cm	Means	5cm	10cm	15cm	Means
C	17.0	16.2	16.0	16.4[b]	16.7	16.7	16.0	16.4[c]
R	17.0	15.7	15.5	16.0[b]	20.8	20.7	18.5	20.0[a]
D	22.0	20.8	19.3	20.7[a]	18.3	18.0	16.5	17.6[b]
M	20.8	20.2	19.2	20.0[a]	18.2	18.2	16.2	17.5[b]
Depth[2] means	19.2[a]	18.2[b]	17.5[c]		18.5[a]	18.4[a]	16.8[b]	

*Each value represents 6 observations.
[abc]Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.
[1]Vertical comparison among treatments for before and after tillage done separately.
[2]Horizontal comparison among depths for before and after tillage done separately.
C=Cultivator
R=Rotavator
D=Disk Harrow
M=Moldboard Plow

to tillage. Highest overall average temperatures (average across treatments and depths) were observed at the semi-arid site (21°C), followed by the humid (19°C) and the sub-humid sites (17°C). The coefficients of variation among the treatment combinations at sites ranged from 2.74 to 5.20, and 3.50 to 6.82 in before and after determinations respectively.

5. Surface Roughness

The surface roughness coefficient data were determined by calculating the standard deviation of the values measured for the height of the 19 pins dropped on the surface of the freshly tilled soil. Table 24 gives the roughness coefficient changes as affected by the tillage operations for all sites. Smaller values indicate smoother surfaces following tillage and the larger values indicate rougher surfaces. The data are shown in Tables 1 through 6 in Appendix E. After to before ratios for each treatments are summarized in Table 25. A summary of significance levels for F-tests is given in Table 23. Table 24 shows mean roughness coefficient, as affected by the tillage operations for all the experimental sites. These data are shown graphically in Figure 24.

Comparisons of means indicate that the After:Before ratio ranges from 1.52 to 2.71 at Islamabad and Faisalabad, where the soil type was clay loam, and that the ratio ranges from

Table 23. Summary of significance levels for analysis of variance for the effect of tillage treatment on surface roughness at Islamabad (I), Faisalabad (F) and Pirsabaq (P)

	Significance levels for F-test					
	Before			After		
Effect	I	F	P	I	F	P
Treatments	0.09	ns	ns	0.05	ns	0.04

ns= Non-significant at the 0.10 level.

Table 24. Mean comparison of Surface Roughness for before and after tillage treatments at Islamabad (I), Faisalabad (F), and Pirsabaq (P)

	Surface Roughness[1] (cm)					
	Before			After		
Trt.	I	F	P	I	F	P
C	0.86	0.59	0.85[b]	1.31[b]	1.60	1.28[bc]
R	0.86	0.56	0.90[b]	2.00[a]	1.50	1.16[c]
D	0.77	0.60	1.03[ab]	2.01[a]	1.23	1.57[ab]
M	0.72	0.65	1.16[a]	1.90[a]	1.39	1.68[a]

[ab]Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.
[1]Vertical comparison were done among the treatments.
C=Cultivator, R=Rotavator
D=Disk Harrow, M=Moldboard Plow

Table 25. After:before ratio for the surface roughness values collected at each sites

Trt.	Islamabad	Faisalabad	Pirsabaq
Cultivator	1.52	2.71	1.50
Rotavator	2.32	2.68	1.29
Disk	2.61	2.05	1.52
Moldboard	2.64	2.14	1.45

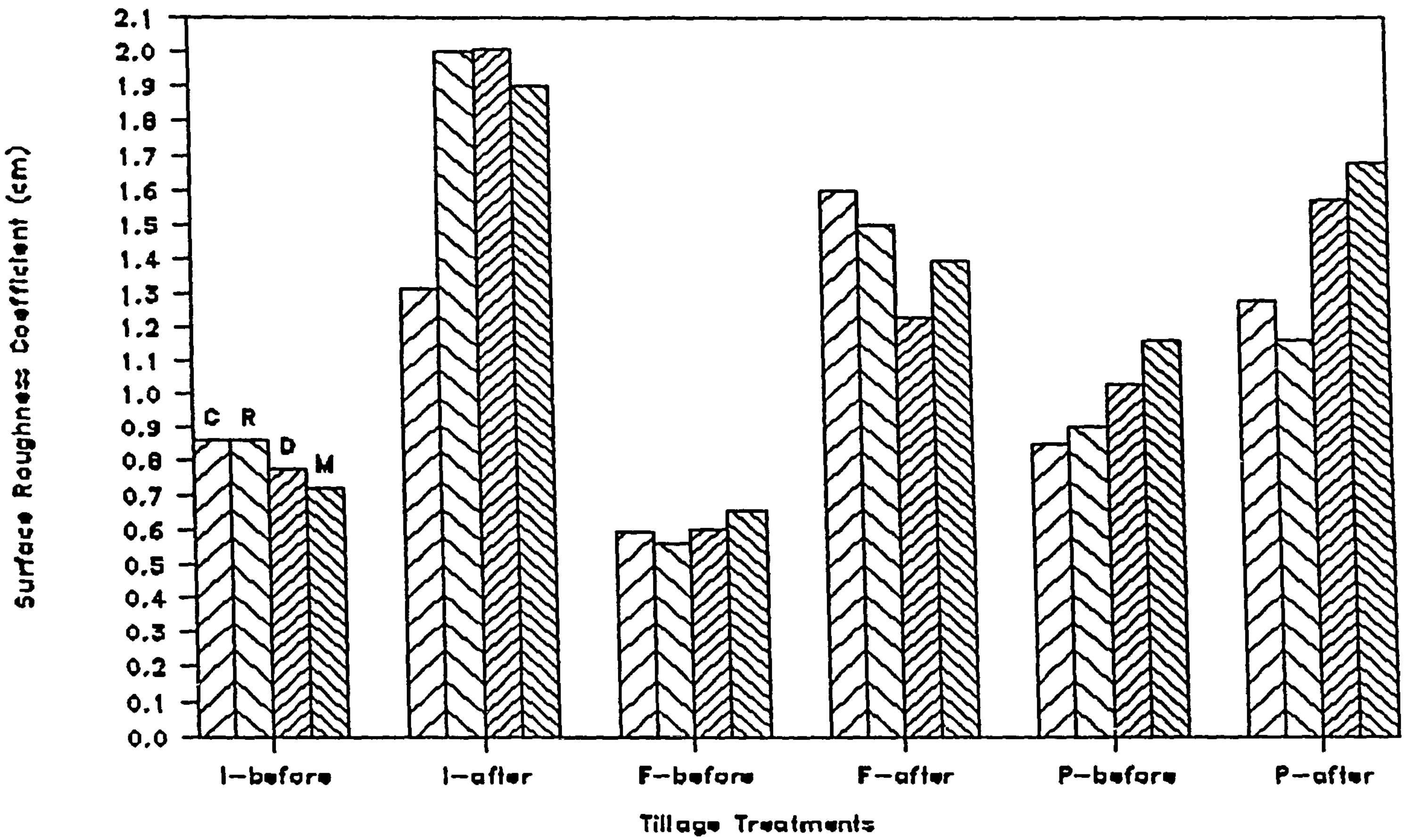

Figure 24. Mean surface roughness coefficient for before and after tillage treatments

1.29 to 1.52 at Pirsabaq, where the soil was sandy clay loam. Distinctly lower values for each treatment were observed for Pirsabaq (Figure 24) compared to the other two sites where the results were comparable, except for cultivator at Islamabad. The surface roughness data for Islamabad (Table 24), show that disking produced the greatest surface roughness (2.01 cm), for Faisalabad, cultivator produced greatest (1.60 cm), and for Pirsabaq moldboard produced a surface roughness (1.68 cm) greater than any of the other tillage operations. At Faisalabad no surface roughnesses were significantly different either before or after tillage. At Islamabad only cultivator showed significantly lower roughness values than the other treatments. At Pirsabaq, moldboard produced highest and rotavator the lowest surface roughnesses after tillage, but the differences were not statistically significant.

Table 23 shows that tillage was significant at 0.05 level in Islamabad and Pirsabaq. Using the surface roughness coefficient, the data show that the plowed soil surface was roughest for all sites and treatments. There seem to have been some slight effects caused by differences in soil moisture content when the tillage was performed, even though all the fields were prepared close to field capacity. The actual moisture content was 4% higher at Islamabad than at the other two sites. It can be seen in Table 24 (and Figure 24) that the general trend was toward rougher surfaces at Islamabad than at Faisalabad and Pirsabaq. This may have been due to higher moisture content at the time of tillage causing larger clod sizes. The smaller standard deviations for Pirsabaq (smoother surface) may be due to the higher sand content there.

6. Tillage Depth

Tool working depth data were recorded at Islamabad, Faisalabad, and Pirsabaq following the tillage operations. The data are shown in Tables 1 through 3 in Appendix F, the mean values are summarized in Table 27, and the analysis of variance is given in Table 26.

Tillage depths were significantly different for the different tillages. Moldboard tilled deepest (19-22 cm), followed by rotavator (9-12 cm), then cultivator (8-10 cm) and disk (5-8 cm). Moldboard was significantly deeper than the other three treatments at all three sites. Similarly, disk was significantly shallower than the others. Cultivator and rotavator were not consistent. At Islamabad both tilled to the same depth, at Faisalabad, rotavator tilled deeper than the cultivator, and at Pirsabaq cultivator was deeper than the rotavator. This variation may be due to operator error, or due to measurement location, which was very critical for the cultivator, because even with 5 passes the

Table 26. Summary of significance levels for analysis of variance for the effect of tillage depth

	Significance levels for F-test		
Effect	Islamabad	Faisalabad	Pirsabaq
Treatments	0.0001	0.0001	0.0001

ns= Non-significant at the 0.10 level.

Table 27. Mean tillage depth under each tillage system at each location

	Location		
Trt.	Islamabad	Faisalabad	Pirsabaq
		-------- cm -----------	
Cultivator	9.38[b]	8.61[c]	9.63[b]
Rotavator	10.90[b]	11.48[b]	8.94[bc]
Disk	6.37[c]	7.08[c]	5.85[c]
Moldboard	20.27[a]	19.24[a]	19.80[a]

[abc]Values of levels of each factor followed by different letters are statistically different at 90 percent Probability level.

cultivator still left some percentage of the area untilled, which was not true for one pass of the rotavator or moldboard plow. The same operator, tractor, and implements were used at each location.

7. Clod Size Distribution

The clod size distribution data are shown in Tables 1,2 and 3 in Appendix G. Table 28 shows the significance levels of F-tests, and Table 29 tabulates the clod mean weight diameters for each treatment at each site. Mass percentage distribution of each clod size group is shown in Table 30.

At Islamabad, the mean weight diameter was the greatest for the moldboard, but it was not different for the remaining three treatments, cultivator, disk and rotavator (Table 29). The mean weight diameters resulting from the analysis of soil aggregate sizes at Faisalabad and Pirsabaq were not statistically different. As an overall average among the treatments, Islamabad and Faisalabad (clay loam) had larger mean weight diameters (13.9 and 13.3 mm respectively) than Pirsabaq (sandy clay loam), where the average was 9.41 mm. This could be related to the moisture content of the soil when the plots were tilled. This moisture content effect was also reflected in the surface roughness data. Aggregates smaller than the 10 mm size group were collected in the bottom tray (pan).

Table 28. Summary of significance levels for analysis of variance for the effect of tillage on mean weight diameter

	Significance levels for F-test		
Effect	Islamabad	Faisalabad	Pirsabaq
Treatments	0.01	ns	ns

ns= Non-significant at the 0.10 level.

Table 29. Mean comparison of mean weight diameter after tillage treatments

	Mean weight diameter (mm)		
Trt.	Islamabad	Faisalabad	Pirsabaq
Cultivator	11.65[b]	10.21[a]	8.09[a]
Rotavator	12.72[b]	16.31[a]	9.02[a]
Disk	11.33[b]	13.34[a]	10.99[a]
Moldboard	19.91[a]	13.34[a]	9.55[a]

[abc]Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.

Table 30. Percentage distribution of soil aggregates on each sieve

		-------Sieve	sizes	(mm)---------				
Sites/Trt.	Pan	10	20	30	40	50	60	70
Islamabad	-----------------			%	----------------------			
Cultivator	70	13	7	5	3	0	0	0
Rotavator	65	15	8	5	2	2	0	0
Disk	70	13	8	4	3	3	0	0
Moldboard	47	15	11	9	6	3	4	3
Faisalabad								
Cultivator	76	9	7	5	2	1	0	0
Rotavator	67	14	9	7	6	2	0	0
Disk	66	13	8	4	3	2	3	0
Moldboard	71	11	6	3	3	0	0	3
Pirsabaq								
Cultivator	84	7	3	3	1	0	0	1
Rotavator	73	16	8	2	0	0	0	0
Disk	65	13	7	2	2	0	0	0
Moldboard	78	9	6	3	0	2	0	0

Table 30 shows that more than 50 percent of the soil mass aggregate simply passed through the sieves and was collected in the pan. At Islamabad and Faisalabad there was some distribution of clod sizes observed up to the 50 mm sieve. But at Pirsabaq only up to 30 mm were observed. Rotavator had the highest percentage of clods on the 10 mm sieve. Rotavator and cultivator did not create any clod larger than 40 mm diameter. In the pan maximum soil mass was collected for cultivator, followed by moldboard, then rotavator and the disk, except at Islamabad where the moldboard and disk switched their positions.

B. Crop Performance as Affected by Tillage

Data for the responses measured are given in Appendices H and I. The analysis of variance tables obtained using PROC GLM programs are presented at the end of each appendix. Tables of means, summary of significance levels for F-tests, and the graphical presentations are included in the text for discussion. The results are discussed here.

1. <u>Seedling Emergence</u>

Seedling counts were taken 7 days after sowing and for the next 14 days. These data are listed in Tables 1, 2, and 3 in Appendix H. Summary of significance for F-test is presented in Tables 31 and 32. Summarized data are given in Tables 33 through 36. Graphical representation of the treatment effects are shown in Figure 25, 26, and 27.

Generally, plant population was greater in moldboard plots, (Table 33) followed by rotavator, then disk and cultivator. Higher emergence rates for maize planted into the moldboard plowed soil were reported by Erbach et al., (1986). Results were not consistent at all sites. At Faisalabad, moldboard and disk had higher populations than cultivator, at Pirsabaq all were similar, but at Islamabad (Table 33) plant population with rotavator was highest, followed by moldboard and cultivator. Means values at Faisalabad and Pirsabaq show cultivator had lowest emergence, and at Islamabad disk emergence was lowest. Comparing site averages, Faisalabad had highest plant population followed by Pirsabaq and Islamabad, even though the same seeding rate and seed drill were used for all sites.

Effect of tillage on emergence was significant only at Faisalabad (Table 31). Effect of time-after-sowing on emergence was highly significant at all sites. Table 32 shows the significance level of treatments for F-tests at each site for each day after emergence counting started. Days 8 to 14 after planting were highly significant for emergence at

Table 31. Summary of significance levels for the analysis of variance for the effect of tillage treatment and days after sowing on emergence count

	Significance levels for F-tests		
Effect	Islamabad	Faisalabad	Pirsabaq
Treatments	ns	0.05	ns
Days	0.0001	0.0001	0.0001
Trt. by days	ns	ns	ns

ns = non significant at the 0.10 level.

Table 32. Summary of significance levels for analysis of variance for the treatment effect on individual day after sowing on emergence count

	Significance levels for F-tests		
Days after sowing	Islamabad	Faisalabad	Pirsabaq
8	0.0001	0.0001	ns
9	0.0001	0.0001	ns
10	0.0002	0.0001	0.05
11	0.002	0.0001	0.004
12	0.003	0.0001	0.01
13	0.002	0.0002	0.0001
14	0.003	0.004	0.001
15	0.05	0.01	ns
16	0.01	ns	ns
17	0.01	0.01	ns
18	0.02	0.03	ns
19	ns	ns	ns

ns = non significant at the 0.10 level.

Table 33. Comparison of emergence count as effected by tillage treatments

	Emergence count (# of plants/m^2)		
Trt.	Islamabad	Faisalabad	Pirsabaq
Cultivator	260^{ab}	158^{b}	293^{a}
Rotavator	324^{a}	202^{ab}	297^{a}
Disk	211^{c}	254^{a}	296^{a}
Moldboard	277^{ab}	286^{a}	297^{a}

^{abc}Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.

Islamabad and Faisalabad with clay loam soil. From days 14 to 17, differences due to treatment were significant only at the 0.01 to 0.05 level, and after day 17 the treatment effect diminished and became non-significant. For the sandy clay loam site, the first two days and the last 6 days showed no differences in germination due to treatments. However, days 10, 11, 12, 13, and 14th after sowing had significant differences in emergence due to treatment. Lower surface roughness and smaller size clods were observed at Pirsabaq, which may indicate that soil-seed contact was favorable in all treatments for emergence.

Variation in emergence occurs when the seeds encounter different environmental conditions. Table 32 clearly shows that at Islamabad and Faisalabad, treatments created different seed environmental conditions which affected the emergence rate. These differences began to diminish by the 15th day after sowing, and by the 19th day all treatment plots show the same trend. Plots at Islamabad had the lowest total emergence, only reaching 310 plants per square meter, 38% less than the optimum number of plants (Figure 25), although the same variety and same certified seed was used at each site. Optimum emergence was 500 plants per square meter, as recommended by the Pakistan Agricultural research Council (PARC, 1988). The only observed cause was attack by birds.

This site was situated between large orchards. Even after appointing a person full time to take care of these birds, attacks by crows were non-controllable. Highest total emergence, up to 456 plants per square meter (Figure 26), was noted at Faisalabad, followed by Pirsabaq (Figure 27), at 350 plants per square meter. These were respectively 9% and 30% lower than the optimum. Reasons for the variation in final plant population among tillage system from site to site are not clear but may be due to interactions among soil types, weather, and tillage.

Tables 34, 35, and 36 show the emergence on each counting day for each treatment. At Islamabad emergence started very fast, but the differences due to the treatments were clear. Rotavator showed consistently higher emergence rate, followed by moldboard, cultivator and disk, up to the 18th day after planting. Table 35 shows delayed emergence with all treatments at Faisalabad; at this site moldboard consistently showed higher emergence followed by disk, rotavator and cultivator, up to the last day of counting. Cultivator had the most delayed emergence. In Table 36 (Pirsabaq), no consistent trend was observed. On days 8 and 9 rotavator was highest, for days 11, 12, and 14, 15, disk was highest and for the remaining days rotavator was again highest. The cultivator treatment never had highest emergence on any day.

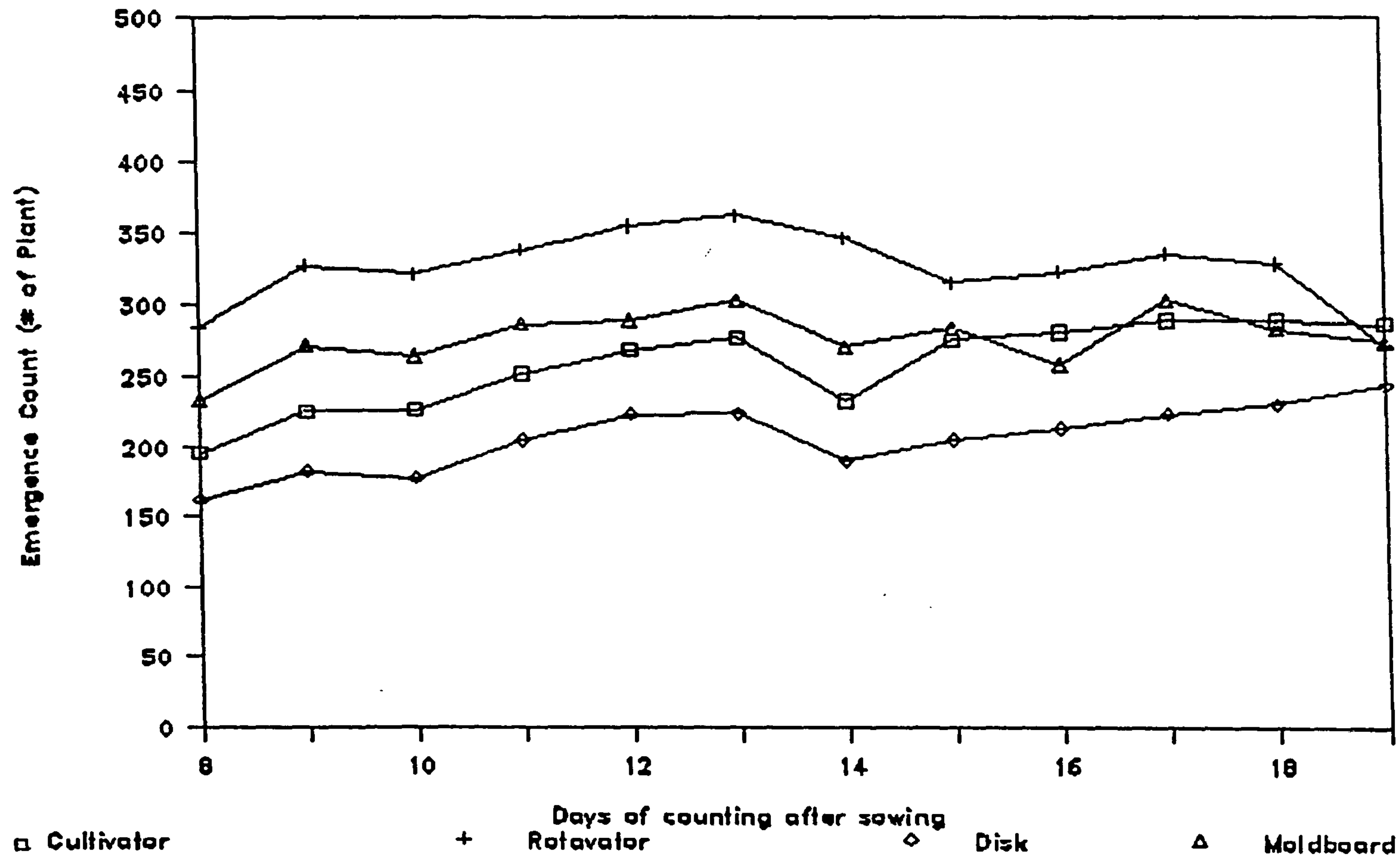

Figure 25. Mean emergence count as affected by tillage at Islamabad

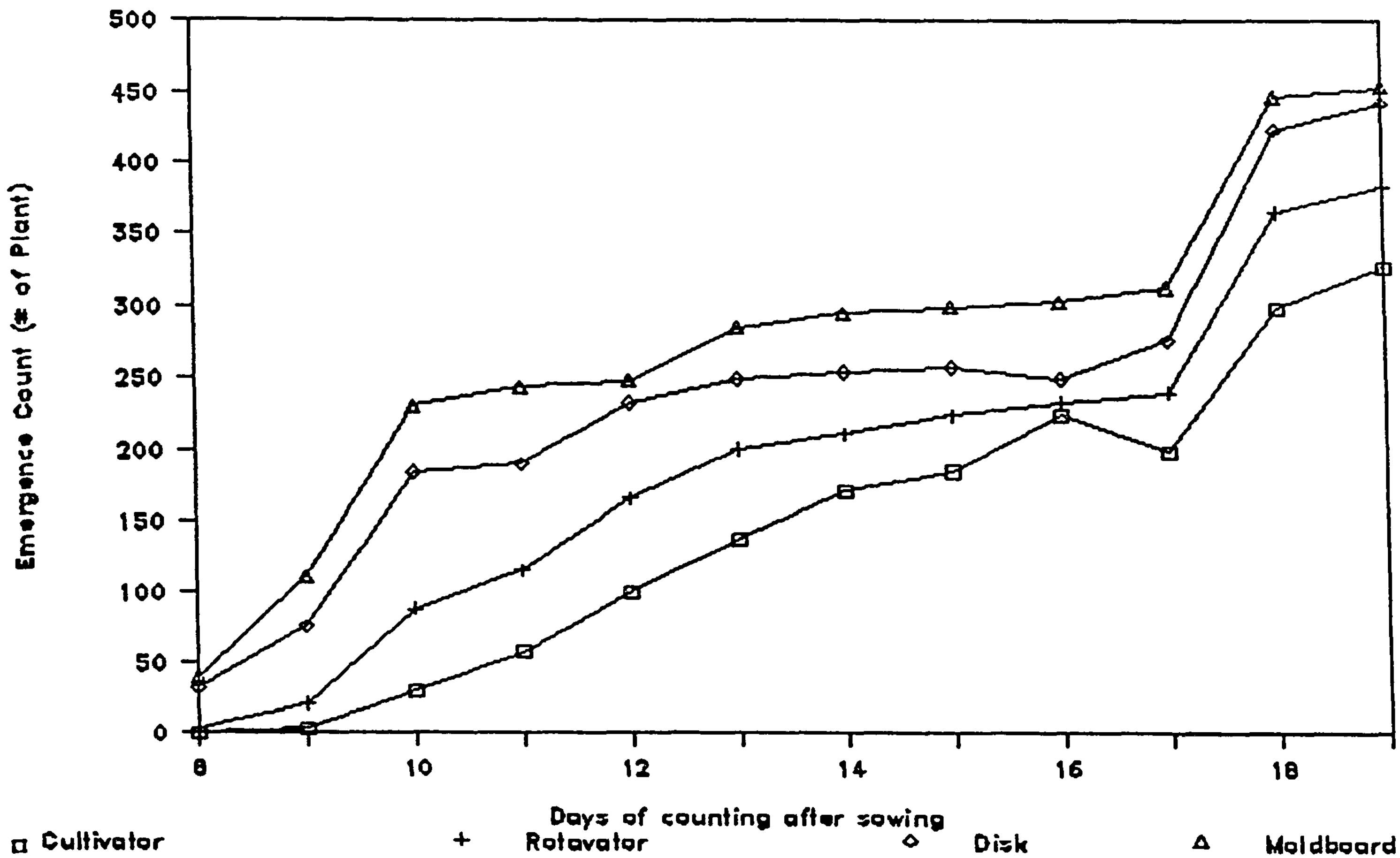

Figure 26. Mean emergence count as affected by tillage at Faisalabad

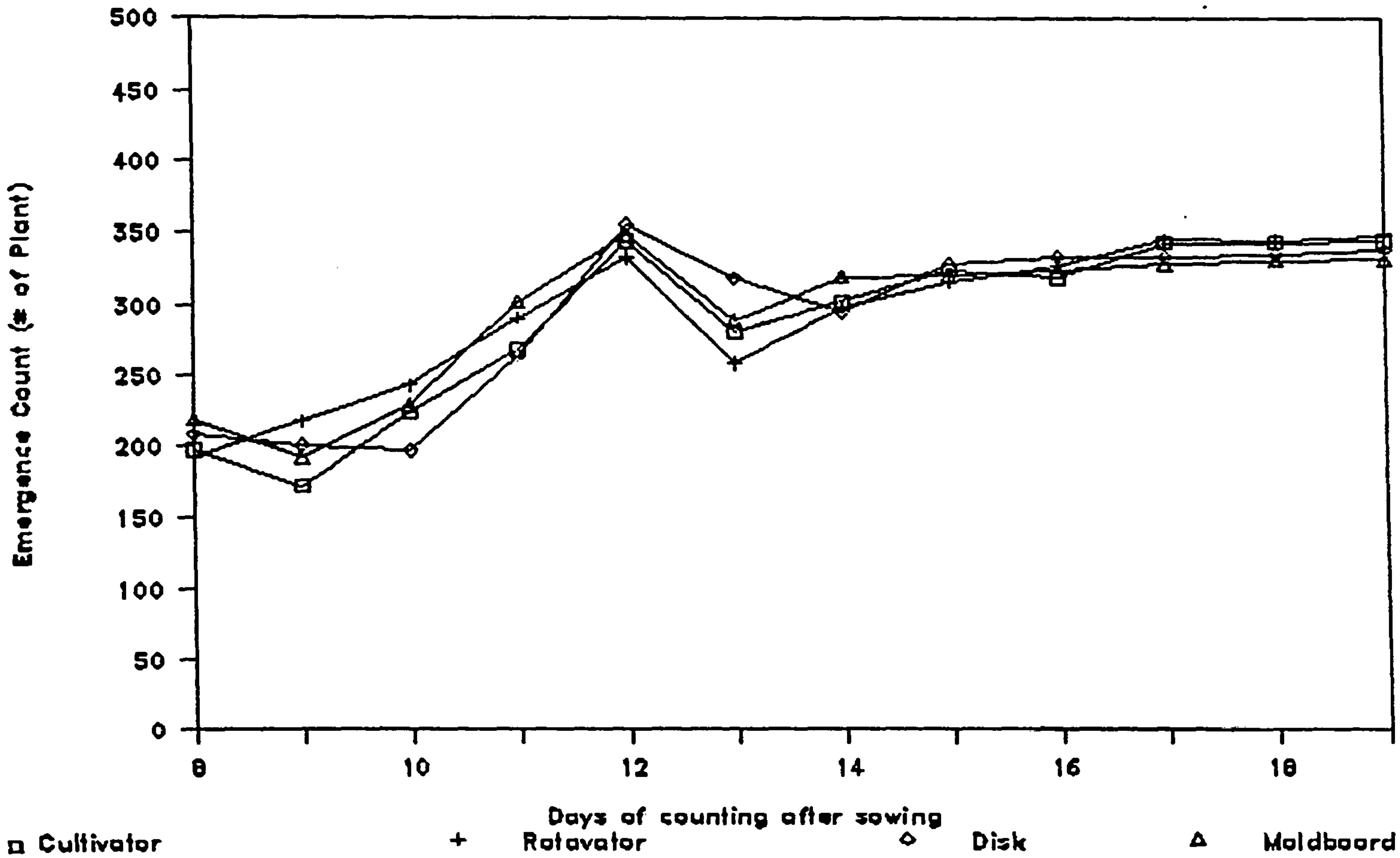

Figure 27. **Mean emergence count as affected by tillage at Pirsabaq**

Table 34. Effect of tillage treatments on mean emergence count at Islamabad (humid, clay loam)

	Emergence count (# of plants/m^2)			
Days after sowing	Cultivator	Rotavator	Disk	Moldboard
8	196	284	162	233
9	225	327	183	271
10	226	321	178	264
11	251	338	205	285
12	268	355	223	288
13	276	363	224	302
14	232	347	190	270
15	275	315	205	283
16	280	322	213	258
17	288	335	223	302
18	288	328	230	282
19	288	310	243	273

Table 35. Effect of tillage treatments on mean emergence count at Faisalabad (semi-arid, clay loam)

	Emergence count (# of plants/m^2)			
Days after sowing	Cultivator	Rotavator	Disk	Moldboard
8	0	3	32	39
9	3	21	75	110
10	30	87	184	230
11	57	115	190	243
12	99	166	232	247
13	137	200	248	284
14	171	211	253	294
15	184	224	256	298
16	224	232	248	302
17	198	239	275	312
18	297	365	423	446
19	326	382	442	453

Table 36. Effect of tillage treatments on mean emergence count at Pirsabaq (sub-humid, sandy clay loam)

	Emergence count (# of plants/m^2)			
Days after sowing	Cultivator	Rotavator	Disk	Moldboard
8	197	193	208	218
9	172	217	200	192
10	224	243	197	229
11	267	290	263	301
12	344	333	355	348
13	280	258	318	288
14	302	298	294	319
15	324	316	328	320
16	318	327	333	323
17	343	345	333	328
18	343	344	335	330
19	349	350	341	335

2. Crop Yield

Crop yield data were collected by using two methods; in method 1 three sample of one meter square were randomly collected from the each field and in method 2, one sample 25 m x 1 m was harvested from each plot. These data are listed in Tables 1, 2, and 3 in Appendix I. Tables 37 and 38 show the effects of the tillage treatment on the wheat yield at the three sites. From the table, there appeared to be consistently higher grain yields for moldboard in all sites, and for both harvesting methods. Similarly, cultivator showed lowest yields for both harvesting methods at Islamabad and Faisalabad, but showed little variation at Pirsabaq. The differences between moldboard and cultivator were larger (2.7 t/ha) for the strip samples (method 2) and (1.2 t/ha) for the meter square samples (method 1) at Islamabad and Faisalabad, but the difference was not as great at Pirsabaq (0.2 t/ha). Higher yields from moldboard plowed treatments than from cultivator treatments were also reported by Khan et al. (1986) for Islamabad and by Sheikh (1983) for Faisalabad. For the square meter technique, moldboard showed a significantly higher yield compared to the other tillage treatments at Islamabad (Table 37). Effect of tillage system was nonsignificant on grain yield at Faisalabad. At Pirsabaq cultivator and moldboard treatments had higher yields and the

Table 37. Comparison of grain yield means as affected by the tillage treatments at Islamabad, Faisalabad, and Pirsabaq

Site	Grain yield (t/ha)			
	Cultivator	Rotavator	Disk	Moldboard
Method 1* (one meter square)				
Islamabad	3.1[b]	3.9[b]	3.9[b]	4.1[a]
Faisalabad	3.6	3.7	4.1	4.3
Pirsabaq	5.8[a]	4.5[b]	5.9[ab]	6.0[a]
Method 2** (25 meter strip)				
Islamabad	4.6	5.1	5.1	6.3
Faisalabad	3.6	4.1	3.9	4.1
Pirsabaq	5.5	4.4	5.3	5.6

*Average of 9 readings.
**Average of 3 readings.
[ab]Values of levels of each factor followed by different letters are statistically different at 90 percent probability level.

Table 38. Comparison of grain yield means for the sites at Islamabad, Faisalabad, and Pirsabaq

	Grain yield (t/ha)			
Site	N	Mean	CV(%)	F-test
Method 1* (one meter square)				
Islamabad	36	3.72	21.9	ns
Faisalabad	36	3.92	45.4	ns
Pirsabaq	36	5.55	21.5	ns
Method 2** (25 meter strip)				
Islamabad	12	5.29	17.7	ns
Faisalabad	12	3.94	10.9	ns
Pirsabaq	12	5.21	5.7	ns

rotavator yield was significantly different from cultivator, disk, and moldboard. For the second method of sampling yield (25 m x 1 m strip), none of the treatments at any site showed any significant difference in grain yield. Mean values of yield at Islamabad and Faisalabad showed a similar trend; yield increased in the order: M > D and R > C, for both yield sampling methods. At Pirsabaq, the first sampling method showed a trend, in the order of: M > D > C > R. For the second method the order was: M > C > D > R. In both cases moldboard was highest and rotavator was lowest. Cultivator and disk switched their position for the different harvesting methods.

Coefficients of variation for one meter square samples were greater (Table 38), Faisalabad (45.4%), Islamabad (21.9%), and Pirsabaq (21.5%), than for the twenty five meter long strip, where the coefficients of variation were 17.7 for Islamabad, 10.9 for Faisalabad, and 5.7 for Pirsabaq.

General Discussion

Table 39 lists values of soil physical properties, wheat emergence, and wheat yields, averaged for all sites after tillage. Lowest bulk densities for rotavator were expected. Rotavator normally over pulverizes the soil, especially if used at field capacity (FMO Tillage, 1976). Disking once following moldboard decreased bulk density more than disking

Table 39. Physical properties effects on wheat yields. Averages of all sites after tillage

Treatment	Properties Measured		
	Yield (t/ha)	Emergence (No. of plants)	Penetration Resistance (kPa)[1]
Cultivator	4.6	237	514
Rotavator	4.5	274	56
Disk	4.8	254	945
Moldboard	5.3	287	260

[1]These values averaged across depth 0-15 cm only.

Density (Mg/m^3)	MWD (mm)	Surface Roughness(cm)	Moisture (%)	Temperature (^oC)
1.01	9.98	1.39	17.4	18.9
0.83	12.68	1.55	18.0	21.2
1.02	11.87	1.60	17.3	18.0
0.96	14.27	1.65	16.6	18.6

twice without plowing. Higher bulk density and penetration resistance for cultivator may be due to the additional passes, which compacted the soil.

Greater bulk density and penetration resistance changes were found at Pirsabaq, sandy clay loam soil, previously in maize, than for corresponding treatments at Islamabad and Faisalabad. This means that the clay loam soil which was previously in rice (Faisalabad) and in fallow (Islamabad) was consolidated more by the tillage treatments than the sandy clay loam. The differences in consolidation could be attributed to the soil type or the soil conditions existing when tillage was performed.

Like penetration resistance (Table 39), bulk density was high for disk and cultivator and was low for rotavator and moldboard. This suggests that soil bulk density and penetration resistance are parallel measurements; however, there is a distinct difference between the two types of measurements. Penetration resistance values for the effects of tillage, showed large changes in magnitude, whereas, smaller changes were detected among soil dry bulk densities for the same effects. Therefore, penetration resistance appears to be a more sensitive indicator of soil compaction than dry density of soil. This is further supported by Voorhees et al., (1978). Lowest overall average penetration resistance for

Islamabad may be related to higher moisture contents in these plots. Soil resistance to penetration was more responsive to soil type than to tillage effect.

Bulk density may have been affected by moisture distribution within the profile. Similar moisture contents resulted in similar bulk densities for cultivator and disk (Table 39). In general, it can be concluded from these bulk density data that the differences in the data between the various experiments are probably due primarily to soil type, moisture content and initial soil condition, but these data are insufficient to draw definite conclusions about how these variables affect the bulk density changes caused by tillage operations.

Soil moisture content at the humid site (Islamabad) was higher (20%) than at the other two sites. Islamabad also showed relatively higher bulk density, which facilitates the unsaturated upward movement of water. This may be the reason for the moisture gradient. Before-tillage values for moisture content mean at Islamabad suggested that tillage was carried out at a higher moisture (21.5%) than at Faisalabad (15.1%) and Pirsabaq (17.5%) and resulted in higher moisture after tillage at Islamabad (20.2%) than at Faisalabad (16.1%) and Pirsabaq (15.7%). Data were collected one day after tillage to observe the soil drying rates between treatments.

Continuous data collection for several days would have been a better approach.

It is apparent that measurements of bulk density and moisture content alone are insufficient for predicting penetration resistance (Table 39). The same difficulties were encountered by Chesness et al., (1972) and Elamin (1983) when they tried to relate bulk density and moisture to soil strength. Moldboard plots showed highest aggregate mean weight diameter and surface roughness. This was logical since moldboard usually leaves large air spaces and clods in the tilled layer, which is conducive to forming a rough surface. There was a general trend toward smoother surfaces and smaller mean weight diameter as soil sand content increased.

Higher yields in moldboard plots correspond to higher emergence; moldboard left large voids and rougher surfaces, which might have contributed to better emergence and yield. Rotavator on the other hand over pulverized the soil, and reflected the lowest penetration resistance and lowest bulk density. This condition definitely did not encourage the wheat yield, higher emergence after moldboard may be due to the better seed contact at sowing, but in the later part of the season small particles may have plugged the voids, limiting the air and water movement and consequently limiting root penetration.

The results of this study can help in determining the kind and amount of tillage to perform on a soil. They also provide a basis for the selection of superior tillage systems for different regions of Pakistan. For example, moldboard created a superior seed environment in the arid region and rotavator in the humid region. Additional passes of cultivator did not influence plant emergence, rather adverse effects on bulk density and penetration resistance may be observed.

VI SUMMARY AND CONCLUSIONS

Interest in tillage research on specific crops, soil types, soil conditions, and seed environmental conditions in specific geographical areas, prompted this study to investigate the effects of tillage on soil physical properties, and consequently on seed emergence and yield, at three ecologically different sites in Pakistan.

Four tillage treatments, namely cultivator (5 passes), rotavator (once), disking (twice), and moldboard plus disking, were applied. Prior to tillage , baseline data for bulk density, moisture content, soil temperature, penetration resistance and surface roughness were collected. After tillage, these parameters and the tillage depth and aggregate size were also measured. Emergence counts were carried out from seven day after sowing to the 19th day. Finally the wheat yield samples were collected using two methods of yield estimation; square meter samples and a strip across the whole plot.

Bulk density was significantly different for tillage and depth at all sites. Higher values of bulk density were observed for clay loam compared to the sandy clay loam. No consistent trends for tillage practices were observed. However, the overall bulk densities were lowest for rotavator and highest for disk. Rotavator produced greater bulk density change than moldboard; cultivator and disk were the same. Sandy clay loam had 6% greater bulk density change than the clay loam. Bulk density decrease was greater for 0 to 5 cm followed by 5 to 10 cm and 10 to 15 cm.

Soil moisture content showed no significant difference due to tillage. Moisture contents for the humid region were higher than for the sub-humid and semi-arid.

Penetration resistance values for tillage and depth showed highly significant effects. Soil strength increased with increasing soil depth. Major differences in penetration resistance for before and after values were observed in the 0 to 15 cm soil profile, and the differences narrowed at lower depths. The change in penetration resistance due to tillage for sandy clay loam was 16% more than for the clay loam. Moldboard showed greatest decrease in resistance after tillage, followed by rotavator. Sandy clay loam showed greater change (55%) compared to clay loam (34%).

Soil temperature showed significant differences with treatment and with depth after tillage, but the results were not consistent. Highest soil temperature were observed at 0 to 5 cm profile and lowest at 10-15 cm profile. Highest overall average among the treatments and depths were observed at the semi-arid site, followed by humid and sub-humid.

Soil surface roughness coefficient data show that the soil surface for plots receiving the tillage treatments was rougher than unplowed at all sites. This was expected since plowing usually leaves larger air spaces and clods in the tilled layer which is conducive to forming a rough surface. Some effect of moisture content on surface roughness was observed. Higher moisture contents produced rougher surfaces. The consistency of data for the experiments performed on the same soil type shows that the soil type influenced roughness more than the change in moisture content.

Moldboard depth was 22 cm, rotavator was 12 cm, cultivator 10 cm, and disk 8 cm. Tillage depth data relate directly to the percentage change in penetration resistance with depth.

Mean weight diameter of soil clods was not significantly different for the treatments. Rotavator and cultivator did not create any clods larger than 40 mm diameter. Mean weight diameter at the Islamabad site, also showed effect of moisture content at the time of tillage. Higher moisture content sites had larger clod sizes.

Emergence was greater in moldboard plots, followed by rotavator, then disk and cultivator. Faisalabad had highest plant populations, followed by Pirsabaq and Islamabad, but the rate of emergence at Faisalabad was lower than at the other two sites. Treatment effects on emergence were observed at all sites up to 15 days after sowing, and then diminished with time. For the clay loam soils, differences due to treatment were evident from the start of emergence to the last day of counting, but in the sandy clay loam, differences were observed only for days 11 to 14 after sowing.

Wheat yields were significantly greater in moldboard plots at all sites, compared to the other plots. Lowest yields were observed for cultivator. Emergence was also higher for moldboard plots, and lowest for cultivator. It may be that the plants that emerged late (cultivator) lost their vigor in emergence and yielded less. None of the treatments resulted in a significant difference in yields. At Islamabad bulk density was higher in cultivator plots which may have resulted in lower emergence and yield. Flocker (1976) found one day delay in emergence for tomato seedlings at the soil bulk density of 1.7 Mg/m^3 as compared to 1.10 Mg/m^3. However, the greatest bulk density in these experiments was 1.23 Mg/m^3.

The following conclusions were drawn from the study:

1. No consistent trends for tillage practices on bulk density and penetration resistances were observed. Bulk densities were lowest for rotavator and highest for disk. Penetration resistance were lowest for moldboard followed by rotavator.

2. Major differences in penetration resistance and bulk density for before and after values were observed in the 0 to 15 cm soil profile, and the differences narrowed at greater depths.

3. Effect of soil bulk density and penetration resistance on emergence was observed. Lower values corresponded to higher emergence in moldboard treatments.

4. Neither clod size distribution nor surface roughness data showed consistent differences which could be attributed to the tillage operations.

5. Different tillage treatments did not show a significant effect on grain yield.

6. Clay loam under humid conditions exhibited early emergence but lower plant population. In semi-arid conditions, clay loam exhibited late emergence, but highest total plant population. This indicate that the one soil type can behave differently in different temperature and rainfall zones.

Suggested Future Work

1. It is difficult to draw decisive conclusions from a one-year study. It is important to further replicate this investigation on more crops, soil types, and agro-ecological regions.

2. To study the effect of soil moisture content and temperature on yield requires continuous monitoring of these parameters throughout the growing season, instead of observing just before and after the tillage treatments.

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APPENDIX A: DRY SOIL BULK DENSITY DATA

Table A.1. Dry soil bulk density as observed before and after tillage with different depths at Islamabad

				Bulk Density (Mg/m^3)	
				Tillage	
Trt.	Rep.	Loc.	Depth	Before	After
C	1	1	2	1.244	1.034
C	1	2	2	1.216	1.287
C	1	1	4	1.230	1.116
C	1	2	4	1.276	1.276
C	1	1	6	1.176	1.201
C	1	2	6	1.269	1.297
C	2	1	2	1.237	1.216
C	2	2	2	1.219	1.059
C	2	1	4	1.244	1.219
C	2	2	4	1.162	1.070
C	2	1	6	1.155	1.265
C	2	2	6	1.159	1.212
C	3	1	2	1.271	1.146
C	3	2	2	1.219	1.203
C	3	1	4	1.155	1.233
C	3	2	4	1.240	1.248
C	3	1	6	1.233	1.176
C	3	2	6	1.141	1.223
R	1	1	2	1.233	0.810
R	1	2	2	1.201	0.725
R	1	1	4	1.226	0.881
R	1	2	4	1.283	0.654
R	1	1	6	1.258	0.917
R	1	2	6	1.390	0.762
R	2	1	2	1.265	0.718
R	2	2	2	1.180	0.746
R	2	1	4	1.168	0.768
R	2	2	4	1.191	0.641
R	2	1	6	1.239	1.088
R	2	2	6	1.351	0.913
R	3	1	2	1.173	0.700
R	3	2	2	1.178	0.661
R	3	1	4	1.216	0.707
R	3	2	4	1.251	0.899
R	3	1	6	1.210	0.981
R	3	2	6	1.191	0.785
D	1	1	2	1.258	1.048
D	1	2	2	1.205	0.942
D	1	1	4	1.312	0.967

Table A.1. (Continued)

Trt.	Rep.	Loc.	Depth	Bulk Density (Mg/m^3) Tillage Before	After
D	1	2	4	1.240	0.832
D	1	1	6	1.246	1.185
D	1	2	6	1.217	1.162
D	2	1	2	1.216	1.052
D	2	2	2	1.312	0.935
D	2	1	4	1.287	1.169
D	2	2	4	1.162	1.084
D	2	1	6	1.272	1.233
D	2	2	6	1.130	1.020
D	3	1	2	1.253	0.672
D	3	2	2	1.240	0.945
D	3	1	4	1.232	0.931
D	3	2	4	1.248	1.201
D	3	1	6	1.276	1.127
D	3	2	6	1.283	1.265
M	1	1	2	1.233	0.792
M	1	2	2	1.139	0.938
M	1	1	4	1.173	0.888
M	1	2	4	1.095	0.942
M	1	1	6	1.216	0.977
M	1	2	6	1.194	0.981
M	2	1	2	1.214	0.864
M	2	2	2	1.175	0.768
M	2	1	4	1.152	0.839
M	2	2	4	1.160	0.849
M	2	1	6	1.152	0.910
M	2	2	6	1.269	0.938
M	3	1	2	1.123	0.661
M	3	2	2	1.248	1.041
M	3	1	4	1.194	0.792
M	3	2	4	1.109	1.027
M	3	1	6	1.141	0.867
M	3	2	6	1.107	0.899

Table A.2. Dry soil bulk density as observed before and after tillage with different depths at Faisalabad

				Bulk Density (Mg/m^3)	
				Tillage	
Trt.	Rep.	Loc.	Depth	Before	After
C	1	1	2	1.259	1.102
C	1	2	2	1.248	1.028
C	1	1	4	1.344	1.003
C	1	2	4	1.294	1.141
C	1	1	6	1.394	1.216
C	1	2	6	1.426	1.060
C	2	1	2	1.330	0.971
C	2	2	2	1.262	.
C	2	1	4	1.380	0.892
C	2	2	4	1.333	1.003
C	2	1	6	1.312	1.145
C	2	2	6	1.308	1.209
C	3	1	2	1.284	0.725
C	3	2	2	1.159	0.825
C	3	1	4	1.383	0.860
C	3	2	4	1.287	0.999
C	3	1	6	1.301	0.907
C	3	2	6	1.390	1.212
R	1	1	2	1.319	0.839
R	1	2	2	1.415	0.750
R	1	1	4	1.312	0.868
R	1	2	4	1.394	0.843
R	1	1	6	1.337	0.885
R	1	2	6	1.316	0.839
R	2	1	2	1.308	0.711
R	2	2	2	1.227	0.768
R	2	1	4	1.390	.
R	2	2	4	1.227	0.690
R	2	1	6	1.255	0.775
R	2	2	6	1.259	0.839
R	3	1	2	1.252	0.715
R	3	2	2	1.365	0.896
R	3	1	4	1.326	0.836
R	3	2	4	1.433	0.821
R	3	1	6	1.301	0.857
R	3	2	6	1.348	0.839
D	1	1	2	1.355	0.967
D	1	2	2	1.308	0.942
D	1	1	4	1.401	1.013
D	1	2	4	1.266	0.985
D	1	1	6	0.999	1.063
D	1	2	6	1.291	1.116

Table A.2. (Continued)

Trt.	Rep.	Loc.	Depth	Tillage Before	Tillage After
				Bulk Density (Mg/m^3)	
D	2	1	2	1.323	1.116
D	2	2	2	1.276	1.035
D	2	1	4	1.340	1.212
D	2	2	4	1.412	0.932
D	2	1	6	1.444	1.351
D	2	2	6	1.376	1.180
D	3	1	2	1.209	1.102
D	3	2	2	1.262	0.967
D	3	1	4	1.259	1.305
D	3	2	4	1.284	1.351
D	3	1	6	1.344	1.429
D	3	2	6	1.305	1.301
M	1	1	2	1.323	1.074
M	1	2	2	1.412	0.946
M	1	1	4	1.401	1.241
M	1	2	4	1.351	0.921
M	1	1	6	1.380	1.152
M	1	2	6	1.365	0.964
M	2	1	2	1.308	0.967
M	2	2	2	1.291	1.067
M	2	1	4	1.358	1.131
M	2	2	4	1.340	1.316
M	2	1	6	1.308	1.156
M	2	2	6	1.372	1.280
M	3	1	2	1.305	0.946
M	3	2	2	1.308	1.045
M	3	1	4	1.280	0.953
M	3	2	4	1.255	1.077
M	3	1	6	1.305	1.074
M	3	2	6	1.383	1.020

Table A.3. Dry soil bulk density as observed before and after tillage with different depths at Pirsabaq

				Bulk Density (Mg/m^3)	
				Tillage	
Trt.	Rep.	Loc.	Depth	Before	After
C	1	1	2	1.127	0.757
C	1	2	2	1.166	0.700
C	1	1	4	1.248	0.992
C	1	2	4	1.244	0.949
C	1	1	6	1.301	0.999
C	1	2	6	1.230	1.116
C	2	1	2	1.184	0.540
C	2	2	2	1.205	0.718
C	2	1	4	1.248	0.810
C	2	2	4	1.141	0.757
C	2	1	6	1.120	0.853
C	2	2	6	1.159	0.967
C	3	1	2	1.216	0.707
C	3	2	2	1.156	0.728
C	3	1	4	1.255	0.942
C	3	2	4	1.109	0.711
C	3	1	6	1.180	0.814
C	3	2	6	1.166	0.952
R	1	1	2	1.330	0.775
R	1	2	2	1.262	0.800
R	1	1	4	1.159	0.995
R	1	2	4	1.223	0.856
R	1	1	6	1.305	0.796
R	1	2	6	1.230	0.817
R	2	1	2	1.173	0.867
R	2	2	2	1.294	0.892
R	2	1	4	1.276	1.102
R	2	2	4	1.216	0.796
R	2	1	6	1.177	0.771
R	2	2	6	1.230	0.938
R	3	1	2	1.148	0.800
R	3	2	2	1.223	0.849
R	3	1	4	1.209	0.860
R	3	2	4	1.013	0.906
R	3	1	6	1.106	0.867
R	3	2	6	1.145	0.974
D	1	1	2	1.070	0.750
D	1	2	2	1.159	0.867
D	1	1	4	1.141	1.095

Table A.3. (Continued)

Trt.	Rep.	Loc.	Depth	Bulk Density (Mg/m^3) Tillage Before	After
D	1	2	4	1.252	0.839
D	1	1	6	1.316	0.800
D	1	2	6	1.244	1.077
D	2	1	2	1.198	0.796
D	2	2	2	1.191	0.835
D	2	1	4	1.202	1.080
D	2	2	4	1.191	0.945
D	2	1	6	1.188	0.885
D	2	2	6	1.344	1.080
D	3	1	2	1.134	0.888
D	3	2	2	1.198	0.949
D	3	1	4	1.195	0.896
D	3	2	4	1.173	0.746
D	3	1	6	1.230	0.718
D	3	2	6	1.273	1.009
M	1	1	2	1.166	0.856
M	1	2	2	1.212	0.910
M	1	1	4	1.259	0.881
M	1	2	4	1.148	0.974
M	1	1	6	1.177	0.910
M	1	2	6	1.234	0.981
M	2	1	2	1.152	0.864
M	2	2	2	1.124	0.892
M	2	1	4	1.163	1.002
M	2	2	4	1.284	0.949
M	2	1	6	1.269	1.041
M	2	2	6	1.159	0.988
M	3	1	2	1.209	0.864
M	3	2	2	1.284	0.942
M	3	1	4	1.195	0.970
M	3	2	4	1.241	0.949
M	3	1	6	1.173	0.903
M	3	2	6	1.202	0.960

Table A.4. Analysis of variance of bulk density

Source	DF	Islamabad	Faisalabad	Pirsabaq
		F-values		
Before Tillage				
Trt. plts	3	6.74***	< 1	< 1
Rep(plt) Error (a)	8	--	--	--
Loc(plt*rep) Error (b)	12	--	--	--
Depth	2	< 1	1.84	1.29
Plt*depth	6	2.12	< 1	2.63*
Rep*depth(plt) Error (c)	16	--	--	--
Error (d)	24	--	--	--
Corr. Total	71			
After Tillage				
Trt.	3	145.69***	8.28***	3.34**
Rep(trt) Error (a)	8	--	--	--
Loc(trt*Rep) Error (b)	12	--	--	--
Depth	2	13.02***	17.04***	11.35***
Trt*Depth	6	1.11	1.65	2.24*
Rep*depth(trt) Error (c)	16	--	--	--
Error (d)	24	--	--	--
Corr. Total	71			

*Significant at 0.10 probability level.
**Significant at 0.05 probability level.
***Significant at 0.01 probability level.

APPENDIX B: SOIL MOISTURE CONTENT DATA

Table B.1. Soil moisture content as observed before and after tillage with different depths at Islamabad

Trt.	Rep.	Loc.	Depth	Moisture content (%) Tillage Before	After
C	1	1	2	20.57	22.34
C	1	2	2	19.00	19.06
C	1	1	4	22.54	22.61
C	1	2	4	18.10	21.44
C	1	1	6	22.05	21.89
C	1	2	6	21.28	20.55
C	2	1	2	20.97	18.13
C	2	2	2	17.49	22.81
C	2	1	4	22.00	20.12
C	2	2	4	22.62	25.25
C	2	1	6	20.92	19.94
C	2	2	6	21.16	19.65
C	3	1	2	21.53	17.36
C	3	2	2	18.65	18.32
C	3	1	4	22.76	22.48
C	3	2	4	20.05	21.94
C	3	1	6	21.61	21.15
C	3	2	6	21.80	16.86
R	1	1	2	25.93	16.67
R	1	2	2	23.66	24.51
R	1	1	4	26.66	21.77
R	1	2	4	16.34	19.56
R	1	1	6	20.90	24.81
R	1	2	6	14.57	23.31
R	2	1	2	20.22	19.80
R	2	2	2	11.44	16.67
R	2	1	4	15.52	19.44
R	2	2	4	24.17	14.96
R	2	1	6	22.95	15.03
R	2	2	6	19.73	17.89
R	3	1	2	28.18	22.84
R	3	2	2	26.24	21.50
R	3	1	4	14.03	21.10
R	3	2	4	17.32	18.18
R	3	1	6	20.26	22.10
R	3	2	6	14.02	19.46
D	1	1	2	16.66	21.02
D	1	2	2	13.56	18.87
D	1	1	4	18.15	18.38

Table B.1. (Continued)

Trt.	Rep.	Loc.	Depth	Moisture Content (%) Tillage Before	After
D	1	2	4	17.47	21.36
D	1	1	6	18.25	17.99
D	1	2	6	18.39	19.27
D	2	1	2	17.25	19.59
D	2	2	2	17.07	21.29
D	2	1	4	16.57	18.54
D	2	2	4	21.10	20.00
D	2	1	6	21.78	17.86
D	2	2	6	22.64	22.65
D	3	1	2	22.12	18.52
D	3	2	2	20.34	19.55
D	3	1	4	21.35	20.99
D	3	2	4	19.94	18.05
D	3	1	6	20.33	21.77
D	3	2	6	21.32	17.13
M	1	1	2	22.47	17.49
M	1	2	2	24.64	23.86
M	1	1	4	24.24	20.80
M	1	2	4	28.24	21.13
M	1	1	6	23.97	18.18
M	1	2	6	26.78	24.64
M	2	1	2	27.52	20.98
M	2	2	2	22.08	21.29
M	2	1	4	30.24	21.61
M	2	2	4	24.50	20.92
M	2	1	6	28.39	20.70
M	2	2	6	23.80	20.45
M	3	1	2	25.63	19.89
M	3	2	2	28.20	20.82
M	3	1	4	26.19	18.83
M	3	2	4	30.44	19.03
M	3	1	6	26.47	22.54
M	3	2	6	21.50	19.37

Table B.2. Soil moisture content as observed before and after tillage with different depths at Faisalabad

Trt.	Rep.	Loc.	Depth	Moisture content (%) Tillage Before	After
C	1	1	2	11.62	13.22
C	1	2	2	11.78	11.76
C	1	1	4	14.84	15.60
C	1	2	4	14.34	14.01
C	1	1	6	15.14	17.25
C	1	2	6	15.26	20.80
C	2	1	2	13.40	12.82
C	2	2	2	13.52	.
C	2	1	4	15.50	15.13
C	2	2	4	14.13	14.18
C	2	1	6	15.22	16.14
C	2	2	6	12.88	16.17
C	3	1	2	15.24	11.27
C	3	2	2	17.59	11.20
C	3	1	4	14.13	24.38
C	3	2	4	14.17	12.45
C	3	1	6	15.31	14.50
C	3	2	6	14.30	16.71
R	1	1	2	12.49	15.25
R	1	2	2	14.35	16.58
R	1	1	4	14.12	13.93
R	1	2	4	16.84	18.14
R	1	1	6	13.37	17.26
R	1	2	6	16.56	15.25
R	2	1	2	10.98	27.00
R	2	2	2	10.47	16.66
R	2	1	4	12.50	.
R	2	2	4	13.67	16.49
R	2	1	6	13.35	14.67
R	2	2	6	17.29	15.25
R	3	1	2	15.92	17.41
R	3	2	2	11.75	15.07
R	3	1	4	14.76	17.44
R	3	2	4	14.63	21.21
R	3	1	6	14.51	18.67
R	3	2	6	14.08	14.40
D	1	1	2	15.05	15.07
D	1	2	2	13.68	15.47
D	1	1	4	15.21	16.49
D	1	2	4	14.36	18.41
D	1	1	6	21.09	18.39
D	1	2	6	16.50	16.24

Table B.2. (Continued)

Trt.	Rep.	Loc.	Depth	Tillage Before	After
				Moisture content (%)	
D	2	1	2	12.63	15.92
D	2	2	2	16.26	15.46
D	2	1	4	19.40	21.40
D	2	2	4	16.42	16.41
D	2	1	6	15.84	13.42
D	2	2	6	16.36	17.46
D	3	1	2	17.69	14.51
D	3	2	2	16.12	13.97
D	3	1	4	16.79	20.43
D	3	2	4	16.34	15.26
D	3	1	6	17.74	12.93
D	3	2	6	14.75	16.66
M	1	1	2	15.93	15.23
M	1	2	2	13.62	17.29
M	1	1	4	17.31	13.46
M	1	2	4	15.81	16.98
M	1	1	6	18.60	20.37
M	1	2	6	16.15	15.49
M	2	1	2	13.68	15.07
M	2	2	2	17.11	17.33
M	2	1	4	17.38	12.89
M	2	2	4	16.70	21.62
M	2	1	6	13.98	16.61
M	2	2	6	16.82	12.77
M	3	1	2	14.45	13.53
M	3	2	2	16.38	14.96
M	3	1	4	16.10	16.41
M	3	2	4	16.15	16.17
M	3	1	6	16.95	14.56
M	3	2	6	15.73	16.02

Table B.3. Soil moisture content as observed before and after tillage with different depths at Pirsabaq

				Moisture Content (%)	
				Tillage	
Trt.	Rep.	Loc.	Depth	Before	After
C	1	1	2	17.35	13.62
C	1	2	2	17.68	12.69
C	1	1	4	15.67	12.90
C	1	2	4	19.43	15.73
C	1	1	6	18.31	16.73
C	1	2	6	16.47	18.47
C	2	1	2	18.32	16.45
C	2	2	2	17.70	15.84
C	2	1	4	16.81	16.67
C	2	2	4	18.38	19.72
C	2	1	6	20.32	20.83
C	2	2	6	20.25	18.38
C	3	1	2	18.42	16.58
C	3	2	2	16.00	17.56
C	3	1	4	11.61	19.62
C	3	2	4	20.19	14.00
C	3	1	6	20.18	14.41
C	3	2	6	20.12	15.67
R	1	1	2	17.11	18.38
R	1	2	2	17.75	20.00
R	1	1	4	15.95	20.00
R	1	2	4	15.99	16.18
R	1	1	6	15.26	18.75
R	1	2	6	15.03	17.39
R	2	1	2	22.12	18.85
R	2	2	2	17.58	13.94
R	2	1	4	16.43	18.06
R	2	2	4	14.62	10.71
R	2	1	6	19.03	13.82
R	2	2	6	14.16	14.77
R	3	1	2	18.58	19.11
R	3	2	2	18.31	18.83
R	3	1	4	16.18	19.01
R	3	2	4	16.14	15.29
R	3	1	6	17.68	16.80
R	3	2	6	18.63	18.98
D	1	1	2	18.94	17.54
D	1	2	2	19.94	16.80
D	1	1	4	18.38	17.53

Table B.3. (Continued)

Trt.	Rep.	Loc.	Depth	Moisture Content (%) Tillage Before	After
D	1	2	4	19.32	17.80
D	1	1	6	18.11	18.22
D	1	2	6	16.86	17.16
D	2	1	2	20.47	18.75
D	2	2	2	20.30	20.00
D	2	1	4	16.86	18.42
D	2	2	4	18.51	19.17
D	2	1	6	17.96	19.68
D	2	2	6	11.11	19.08
D	3	1	2	14.11	14.00
D	3	2	2	15.13	07.87
D	3	1	4	15.77	15.08
D	3	2	4	17.58	07.14
D	3	1	6	17.63	10.89
D	3	2	6	14.53	11.27
M	1	1	2	11.28	17.84
M	1	2	2	12.61	14.06
M	1	1	4	11.30	16.53
M	1	2	4	15.79	10.22
M	1	1	6	17.82	11.72
M	1	2	6	14.41	13.04
M	2	1	2	17.59	16.87
M	2	2	2	22.78	14.34
M	2	1	4	18.96	12.06
M	2	2	4	19.67	11.61
M	2	1	6	18.49	11.26
M	2	2	6	16.56	12.95
M	3	1	2	22.65	17.70
M	3	2	2	19.94	09.81
M	3	1	4	18.75	11.36
M	3	2	4	22.35	11.61
M	3	1	6	21.21	12.99
M	3	2	6	21.01	13.33

Table B.4. Analysis of variance of moisture content

Source	DF	Islamabad	Faisalabad	Pirsabaq
		F-values		
Before Tillage				
Trt. plts	3	19.14***	12.50***	< 1
Rep(plt) Error (a)	8	--	--	--
Loc(plt*rep) Error (b)	12	--	--	--
Depth	2	< 1	4.16**	1.12
Plt*depth	6	1.27	< 1	1.69
Rep*depth(plt) Error (c)	16	--	--	--
Error (d)	24	--	--	--
Corr. Total	71			
After Tillage				
Trt.	3	< 1	4.39***	1.39
Rep(trt) Error (a)	8	--	--	--
Loc(trt*rep) Error (b)	12	--	--	--
Depth	2	< 1	3.33*	2.07
Trt*depth	6	2.47*	2.11*	3.14*
Rep*depth(trt) Error (c)	16	--	--	--
Error (d)	24	--	--	--
Corr. Total	71			

*Significant at 0.10 probability level.
**Significant at 0.05 probability level.
***Significant at 0.01 probability level.

APPENDIX C: SOIL PENETRATION RESISTANCE DATA

Table C.1. Soil penetration resistance at different depths prior to tillage at Islamabad

			Penetration Resistance (N/cm^2)					
			Depths (cm)					
Trt.	Rep.	Loc.	05	10	15	20	25	30
C	1	1	80	110	110	100	220	230
C	1	2	270	310	430	540	300	200
C	1	3	140	220	140	170	240	290
C	2	1	100	140	120	100	60	120
C	2	2	150	200	300	320	240	200
C	2	3	100	110	90	200	200	160
C	3	1	160	180	240	200	220	440
C	3	2	70	170	170	200	300	200
C	3	3	130	220	200	190	270	180
R	1	1	80	120	120	80	90	120
R	1	2	90	230	200	180	220	220
R	1	3	100	170	180	290	260	140
R	2	1	50	200	250	60	70	80
R	2	2	150	140	170	110	140	120
R	2	3	160	160	180	80	80	180
R	3	1	100	180	230	160	220	190
R	3	2	180	300	290	100	160	220
R	3	3	190	230	340	260	190	180
D	1	1	90	110	160	160	150	170
D	1	2	70	160	80	70	160	140
D	1	3	60	170	190	210	190	180
D	2	1	190	210	200	410	300	240
D	2	2	60	240	260	240	210	240
D	2	3	60	100	70	60	80	100
D	3	1	140	360	460	140	170	180
D	3	2	180	160	180	430	350	250
D	3	3	160	170	120	130	170	280
M	1	1	300	320	290	140	140	130
M	1	2	110	160	150	150	150	150
M	1	3	70	80	100	190	200	200
M	2	1	160	200	120	220	200	200
M	2	2	90	110	130	100	140	150
M	2	3	80	130	140	90	130	180
M	3	1	90	120	100	160	180	180
M	3	2	70	80	120	100	200	190
M	3	3	90	90	160	210	170	170

Table C.2. Soil penetration resistance at different depths as affected by tillage at Islamabad

			Penetration Resistance (N/cm^2)					
			--------Depths(cm)--------					
Trt.	Rep.	Loc.	05	10	15	20	25	30
C	1	1	0	30	310	310	300	260
C	1	2	0	10	0	320	500	600
C	1	3	20	30	140	120	190	210
C	2	1	80	90	230	210	180	140
C	2	2	0	50	100	200	250	180
C	2	3	100	170	120	220	200	180
C	3	1	0	40	80	200	160	160
C	3	2	60	70	260	280	240	210
C	3	3	10	110	150	270	260	190
R	1	1	0	10	25	210	170	200
R	1	2	0	0	30	60	160	130
R	1	3	0	0	0	10	160	190
R	2	1	0	0	10	100	180	110
R	2	2	0	0	0	180	280	180
R	2	3	0	0	0	170	170	200
R	3	1	0	0	10	210	180	180
R	3	2	0	0	5	300	280	200
R	3	3	0	0	0	30	190	170
D	1	1	0	0	170	180	120	180
D	1	2	0	0	160	140	190	190
D	1	3	40	180	210	390	320	320
D	2	1	0	200	240	240	260	260
D	2	2	0	0	240	190	210	210
D	2	3	60	120	260	200	260	240
D	3	1	0	80	170	160	320	300
D	3	2	0	100	140	140	240	240
D	3	3	0	180	360	300	250	200
M	1	1	0	0	60	60	110	140
M	1	2	0	0	40	30	40	10
M	1	3	10	20	40	40	140	140
M	2	1	0	0	50	60	120	140
M	2	2	0	10	80	80	50	180
M	2	3	0	0	0	40	40	70
M	3	1	0	20	120	100	130	160
M	3	2	0	10	100	30	180	180
M	3	3	0	20	30	60	170	160

Table C.3. Soil penetration resistance at different depths prior to tillage at Faisalabad

			Penetration Resistance (N/cm^2)					
			--------Depths(cm)--------					
Trt.	Rep.	Loc.	05	10	15	20	25	30
C	1	1	110	120	310	400	340	290
C	1	2	240	230	300	290	420	-
C	1	3	180	240	250	330	280	190
C	2	1	60	50	260	440	310	220
C	2	2	310	280	260	310	250	200
C	2	3	260	350	360	410	270	200
C	3	1	190	250	260	250	220	210
C	3	2	240	260	300	490	450	330
C	3	3	240	340	320	310	360	340
R	1	1	250	250	340	250	200	200
R	1	2	240	220	220	410	500	330
R	1	3	200	210	280	280	210	170
R	2	1	100	160	160	220	400	330
R	2	2	80	120	230	270	260	260
R	2	3	230	250	180	300	250	300
R	3	1	280	300	240	250	240	240
R	3	2	50	60	290	300	270	270
R	3	3	110	200	200	500	400	290
D	1	1	170	250	330	310	360	280
D	1	2	110	160	250	420	400	330
D	1	3	160	240	150	170	270	310
D	2	1	100	140	320	500	520	340
D	2	2	130	110	270	330	310	210
D	2	3	280	230	360	310	140	110
D	3	1	90	110	110	380	360	240
D	3	2	160	200	480	420	300	230
D	3	3	160	210	340	350	500	290
M	1	1	200	230	180	250	230	210
M	1	2	130	170	170	250	260	210
M	1	3	180	180	180	160	210	330
M	2	1	220	190	400	580	600	340
M	2	2	200	140	340	310	240	210
M	2	3	110	110	160	200	220	210
M	3	1	120	110	350	420	340	200
M	3	2	220	200	340	540	320	300
M	3	3	90	140	420	440	440	300

Table C.4. Soil penetration resistance at different depths as affected by tillage at Faisalabad

			Penetration Resistance (N/cm^2)					
			--------Depths(cm)--------					
Trt.	Rep.	Loc.	05	10	15	20	25	30
C	1	1	0	20	300	340	410	380
C	1	2	0	0	130	270	240	280
C	1	3	0	30	120	250	200	270
C	2	1	0	0	150	300	270	240
C	2	2	0	120	170	250	400	700
C	2	3	0	0	200	360	300	280
C	3	1	0	0	140	340	350	390
C	3	2	0	0	0	460	460	340
C	3	3	0	0	350	440	450	380
R	1	1	0	0	0	230	300	250
R	1	2	0	0	0	120	370	330
R	1	3	0	0	0	100	460	390
R	2	1	0	0	40	210	450	400
R	2	2	0	0	0	90	160	100
R	2	3	0	0	0	330	560	520
R	3	1	0	0	0	130	500	320
R	3	2	0	0	0	130	360	270
R	3	3	0	0	0	150	500	400
D	1	1	0	0	220	440	290	300
D	1	2	0	0	120	100	300	360
D	1	3	0	110	280	300	440	350
D	2	1	0	0	180	400	500	530
D	2	2	0	300	320	400	400	340
D	2	3	20	200	440	540	420	420
D	3	1	40	90	300	360	310	280
D	3	2	120	200	450	410	200	260
D	3	3	180	260	280	620	440	320
M	1	1	0	80	130	100	400	410
M	1	2	0	0	10	40	40	130
M	1	3	10	90	120	120	130	240
M	2	1	0	50	50	80	340	270
M	2	2	0	0	80	20	20	170
M	2	3	0	20	30	40	90	220
M	3	1	30	140	110	170	350	320
M	3	2	0	110	130	110	560	380
M	3	3	20	60	30	320	370	210

Table C.5. Soil penetration resistance at different depths prior to tillage at Pirsabaq

			Penetration Resistance (N/cm^2)					
			--------Depths(cm)--------					
Trt.	Rep.	Loc.	05	10	15	20	25	30
C	1	1	200	680	-	-	-	-
C	1	2	100	220	440	570	660	700
C	1	3	220	320	480	560	620	500
C	2	1	160	420	420	410	340	360
C	2	2	105	110	460	560	505	480
C	2	3	130	390	420	435	320	340
C	3	1	140	380	720	-	-	-
C	3	2	80	95	140	340	460	180
C	3	3	280	460	600	640	580	640
R	1	1	200	260	440	460	380	385
R	1	2	100	220	405	430	440	460
R	1	3	260	390	680	-	-	-
R	2	1	100	260	400	420	480	320
R	2	2	300	580	660	700	-	-
R	2	3	80	140	280	380	510	420
R	3	1	190	380	400	540	540	500
R	3	2	200	260	220	300	440	440
R	3	3	80	120	280	380	400	400
D	1	1	110	300	360	340	360	405
D	1	2	20	90	340	390	380	280
D	1	3	160	280	540	590	560	680
D	2	1	160	200	540	690	-	-
D	2	2	55	175	340	320	300	250
D	2	3	180	320	420	350	350	320
D	3	1	80	140	360	480	560	480
D	3	2	140	400	660	580	540	600
D	3	3	80	200	305	360	400	340
M	1	1	195	210	390	530	560	520
M	1	2	180	280	420	445	480	480
M	1	3	70	405	530	580	690	-
M	2	1	80	180	420	450	340	260
M	2	2	125	265	270	220	300	380
M	2	3	80	180	380	260	240	120
M	3	1	100	140	350	380	380	340
M	3	2	90	200	270	400	405	360
M	3	3	110	300	420	470	380	300

Table C.6. Soil penetration resistance at different depths as affected by tillage at Pirsabaq

			Penetration Resistance (N/cm^2)					
				--------Depths(cm)--------				
Trt.	Rep.	Loc.	05	10	15	20	25	30
C	1	1	0	0	140	320	430	360
C	1	2	0	0	0	130	-	-
C	1	3	0	0	40	80	400	340
C	2	1	0	0	240	260	270	400
C	2	2	0	0	0	50	400	420
C	2	3	0	0	0	230	360	410
C	3	1	0	0	5	280	410	300
C	3	2	0	0	0	130	600	500
C	3	3	0	0	50	480	540	620
R	1	1	0	0	260	460	420	580
R	1	2	0	0	50	340	470	380
R	1	3	0	0	0	240	640	660
R	2	1	0	0	120	440	630	340
R	2	2	0	30	60	340	700	580
R	2	3	0	0	300	540	750	800
R	3	1	0	0	100	540	440	380
R	3	2	0	0	120	360	430	370
R	3	3	0	10	170	610	-	-
D	1	1	0	0	170	420	300	400
D	1	2	0	0	70	420	420	380
D	1	3	0	0	70	300	330	420
D	2	1	0	0	10	260	380	370
D	2	2	0	0	90	260	340	320
D	2	3	0	0	70	310	340	540
D	3	1	0	0	0	400	440	450
D	3	2	0	0	110	310	700	-
D	3	3	0	0	80	200	460	440
M	1	1	0	0	0	20	320	320
M	1	2	0	0	0	70	360	360
M	1	3	0	0	140	140	380	400
M	2	1	0	0	20	60	60	80
M	2	2	0	0	20	20	60	300
M	2	3	0	0	0	60	280	300
M	3	1	0	0	0	70	300	530
M	3	2	0	0	0	20	140	280
M	3	3	0	0	40	80	400	600

Table C.7. Analysis of variance of penetration resistance

Source	DF	Islamabad	Faisalabad	Pirsabaq
		F-values		
Before Tillage				
Trt. plts	3	1.17	< 1	1.53
Rep(plt) Error (a)	8	--	--	--
Loc(plt*rep) Error (b)	24	--	--	--
Depth	5	12.69***	29.12***	94.38***
Plt*depth	15	1.96	< 1	< 1
Rep*depth(plt) Error (c)	40	--	--	--
Error (d)	120	--	--	--
Corr. Total	215			
After Tillage				
Trt.	3	28.02***	6.42***	11.18***
Rep(trt) Error (a)	8	--	--	--
Loc(trt*rep) Error (b)	24	--	--	--
Depth	5	64.68***	107.96***	135.49***
Trt*depth	15	3.83***	5.97***	3.91***
Rep*depth(trt) Error (c)	40	--	--	--
Error (d)	120	--	--	--
Corr. Total	215			

*Significant at 0.10 probability level.
**Significant at 0.05 probability level.
***Significant at 0.01 probability level.

APPENDIX D: SOIL TEMPERATURE DATA

Table D.1. Soil temperature at different depths prior to tillage at Islamabad

Trt.	Rep.	Loc.	Soil Temperature (°C) Depths (cm) 05	10	15
C	1	1	19	18	17
C	1	2	18	18	17
C	2	1	19	17	16
C	2	2	17	17	17
C	3	1	20	18	17
C	3	2	18	18	17
R	1	1	20	18	17
R	1	2	18	20	18
R	2	1	.	.	.
R	2	2	.	.	.
R	3	1	21	19	19
R	3	2	19	22	20
D	1	1	21	20	19
D	1	2	20	22	21
D	2	1	22	21	20
D	2	2	21	19	18
D	3	1	17	17	17
D	3	2	17	17	16
M	1	1	17	17	17
M	1	2	17	17	17
M	2	1	19	17	17
M	2	2	17	18	17
M	3	1	18	17	17
M	3	2	17	16	17

Table D.2. Soil temperature at different depths as affected by tillage at Islamabad

			Soil Temperature (°C)		
			---------Depths (cm)---------		
Trt.	Rep.	Loc.	05	10	15
C	1	1	18	17	17
C	1	2	17	17	17
C	2	1	18	18	19
C	2	2	18	17	18
C	3	1	20	18	17
C	3	2	18	18	17
R	1	1	22	21	20
R	1	2	21	21	20
R	2	1	21	20	19
R	2	2	20	20	21
R	3	1	22	22	20
R	3	2	22	23	21
D	1	1	19	17	17
D	1	2	17	17	17
D	2	1	18	16	17
D	2	2	16	16	16
D	3	1	20	17	17
D	3	2	17	17	17
M	1	1	21	20	19
M	1	2	19	19	19
M	2	1	19	18	18
M	2	2	18	20	19
M	3	1	19	19	18
M	3	2	19	19	19

Table D.3. Soil temperature at different depths prior to tillage at Faisalabad

			Soil Temperature (°C)		
			---------Depths (cm)---------		
Trt.	Rep.	Loc.	05	10	15
C	1	1	17	18	18
C	1	2	18	18	18
C	2	1	18	19	18
C	2	2	19	18	19
C	3	1	18	18	19
C	3	2	18	18	18
R	1	1	18	18	19
R	1	2	18	18	19
R	2	1	20	19	18
R	2	2	19	19	19
R	3	1	18	18	18
R	3	2	18	18	18
D	1	1	17	17	18
D	1	2	17	17	18
D	2	1	17	17	17
D	2	2	17	17	18
D	3	1	16	17	18
D	3	2	17	17	18
M	1	1	24	23	22
M	1	2	25	24	22
M	2	1	24	23	22
M	2	2	25	24	23
M	3	1	24	23	22
M	3	2	24	22	22

Table D.4. Soil temperature at different depths as affected by tillage at Faisalabad

			Soil Temperature (°C)		
			---------Depths (cm)---------		
Trt.	Rep.	Loc.	05	10	15
C	1	1	23	22	22
C	1	2	23	22	21
C	2	1	23	22	21
C	2	2	22	22	21
C	3	1	24	22	21
C	3	2	24	22	21
R	1	1	24	23	22
R	1	2	24	23	23
R	2	1	22	22	21
R	2	2	23	23	23
R	3	1	23	23	22
R	3	2	23	23	22
D	1	1	19	18	18
D	1	2	19	18	18
D	2	1	20	19	18
D	2	2	20	18	18
D	3	1	20	19	19
D	3	2	21	20	19
M	1	1	20	19	19
M	1	2	20	18	18
M	2	1	19	19	18
M	2	2	21	20	19
M	3	1	19	18	18
M	3	2	19	18	18

Table D.5. Soil temperature at different depths prior to tillage at Pirsabaq

			Soil Temperature (°C)		
			---------Depths (cm)---------		
Trt.	Rep.	Loc.	05	10	15
C	1	1	17	16	16
C	1	2	16	16	16
C	2	1	16	16	16
C	2	2	16	16	16
C	3	1	19	17	17
C	3	2	18	16	15
R	1	1	18	16	16
R	1	2	16	15	15
R	2	1	17	16	15
R	2	2	17	16	16
R	3	1	16	15	15
R	3	2	18	16	16
D	1	1	24	22	20
D	1	2	21	20	19
D	2	1	23	21	19
D	2	2	21	20	19
D	3	1	22	21	19
D	3	2	21	21	20
M	1	1	23	22	20
M	1	2	20	20	19
M	2	1	21	21	19
M	2	2	21	20	19
M	3	1	21	20	19
M	3	2	20	18	18

Table D.6. Soil temperature at different depths as affected by tillage at Pirsabaq

			Soil Temperature (°C)		
			---------Depths (cm)---------		
Trt.	Rep.	Loc.	05	10	15
C	1	1	18	17	17
C	1	2	17	16	16
C	2	1	18	16	15
C	2	2	18	15	16
C	3	1	16	15	15
C	3	2	18	16	16
R	1	1	22	20	18
R	1	2	22	19	18
R	2	1	22	20	19
R	2	2	22	20	19
R	3	1	22	19	18
R	3	2	22	19	19
D	1	1	20	18	17
D	1	2	17	16	17
D	2	1	19	16	16
D	2	2	19	17	16
D	3	1	20	17	16
D	3	2	21	18	17
M	1	1	19	18	16
M	1	2	19	17	16
M	2	1	19	17	16
M	2	2	18	16	16
M	3	1	19	17	16
M	3	2	20	19	17

Table D.7. Analysis of variance of soil temperature

Source	DF	Islamabad	Faisalabad	Pirsabaq
		F-values		
Before Tillage				
Trt. plts	3	2.92*	173.7***	71.89***
Rep(plt) Error (a)	8	--	--	--
Loc(plt*rep) Error (b)	12	--	--	--
Depth	2	44.25***	< 1	50.92***
Plt*depth	6	2.63**	7.59***	2.92**
Rep*depth(plt) Error (c)	16	--	--	--
Error (d)	24	--	--	--
Corr. Total	71			
After Tillage				
Trt.	3	23.66***	52.17***	31.80***
Rep(trt) Error (a)	8	--	--	--
Loc(trt*Rep) Error (b)	12	--	--	--
Depth	2	17.44***	15.78***	18.88***
Trt*Depth	6	1.31	< 1	< 1
Rep*depth(trt) Error (c)	16	--	--	--
Error (d)	24	--	--	--
Corr. Total	71			

*Significant at 0.10 probability level.
**Significant at 0.05 probability level.
***Significant at 0.01 probability level.

APPENDIX E: SURFACE ROUGHNESS DATA

Table E.1. Surface roughness prior to tillage at Islamabad

T[1]	R[2]	L[3]	Observations 1	2	3	4	5	6	7	8	9	10
C	1	1	14.0	14.0	14.0	14.5	14.0	14.5	15.0	14.5	15.0	14.0
C	1	2	14.0	14.0	14.0	13.0	13.0	13.5	13.0	13.0	14.0	12.5
C	1	3	13.0	12.0	11.0	11.0	10.5	8.0	10.0	10.5	9.5	12.0
C	2	1	14.0	14.0	14.0	13.5	14.0	14.5	13.0	14.0	14.0	13.5
C	2	2	14.5	14.5	14.5	15.0	14.0	14.0	15.0	15.0	16.0	15.0
C	2	3	12.5	13.0	13.0	13.0	13.0	12.5	12.5	12.5	12.5	11.5
C	3	1	14.0	14.0	14.5	13.0	13.0	12.5	12.5	13.0	13.0	12.0
C	3	2	14.0	14.0	14.0	14.5	13.5	13.0	13.0	13.5	14.0	14.0
C	3	3	14.0	14.0	14.0	13.5	14.5	16.0	16.5	16.0	15.0	16.5
R	1	1	12.5	12.5	13.0	13.0	13.0	13.5	12.5	14.0	13.5	13.5
R	1	2	13.5	13.5	14.0	14.0	15.0	15.0	15.0	14.5	13.0	12.5
R	1	3	15.0	15.0	14.0	14.0	14.0	12.0	13.0	13.0	13.0	12.5
R	2	1	14.0	13.5	14.0	14.5	14.5	14.5	15.0	15.0	14.5	14.0
R	2	2	14.0	14.0	14.0	14.0	13.5	14.0	17.0	14.0	14.0	14.0
R	2	3	14.0	14.0	16.0	13.0	14.0	14.0	14.0	14.0	15.0	12.0
R	3	1	14.0	14.0	14.0	14.0	13.5	14.0	14.0	14.0	13.0	13.0
R	3	2	15.0	13.0	13.0	14.0	15.0	15.0	14.5	15.0	15.0	15.0
R	3	3	14.0	14.0	14.0	15.0	15.0	15.5	14.5	11.0	11.0	13.0
D	1	1	14.0	14.0	14.0	14.0	14.0	14.5	13.5	14.5	14.5	14.0
D	1	2	14.0	15.0	14.0	14.5	15.0	15.0	16.0	15.5	15.0	16.0
D	1	3	12.0	12.0	12.0	12.0	12.0	10.5	12.0	12.0	12.5	12.0
D	2	1	14.5	14.5	14.5	13.5	13.0	13.0	12.5	12.5	13.0	12.5
D	2	2	13.0	13.0	13.0	13.0	12.5	12.5	11.5	12.5	12.5	12.0
D	2	3	12.0	13.0	14.0	13.5	14.0	13.0	13.5	13.5	14.0	12.5
D	3	1	13.0	12.5	13.0	12.5	13.0	12.0	12.5	13.0	14.0	14.0
D	3	2	14.0	14.0	14.5	15.5	15.0	15.5	15.0	15.5	15.0	15.0
D	3	3	14.0	14.0	15.0	14.0	14.0	15.0	14.5	13.5	14.0	13.0
M	1	1	14.5	13.5	14.0	14.0	14.0	12.0	13.0	13.5	13.0	13.0
M	1	2	14.0	14.0	15.0	14.5	13.5	13.5	13.5	14.0	14.0	14.0
M	1	3	14.0	14.0	15.5	15.5	16.0	16.5	15.0	15.0	15.5	15.0
M	2	1	13.5	14.0	14.0	14.0	13.5	14.0	13.0	13.0	14.0	14.0
M	2	2	14.0	13.0	14.0	14.0	13.5	12.0	11.5	12.0	12.0	12.0
M	2	3	14.0	13.5	14.0	15.0	15.0	15.5	16.0	17.0	16.0	16.5
M	3	1	14.0	14.0	14.0	14.0	13.0	12.0	14.0	14.5	13.5	13.5
M	3	2	14.0	14.5	14.5	14.5	14.0	15.0	16.0	14.5	11.0	13.0
M	3	3	15.0	15.0	15.5	15.0	14.0	13.5	14.0	14.0	14.0	14.0

[1] Tillage treatments.
[2] Replications.
[3] Locations.
[4] Standard deviation.

11	12	13	14	15	16	17	18	19	SD[4]
15.0	15.0	15.0	14.0	14.5	14.5	14.5	14.0	14.0	0.41
13.0	14.0	15.0	14.5	15.0	15.0	14.5	15.0	14.5	0.80
12.0	12.0	12.0	12.0	12.0	13.0	13.0	13.0	12.0	1.30
13.0	13.0	13.0	12.0	12.0	12.0	12.0	12.0	11.5	0.91
14.0	17.0	15.0	14.0	14.5	14.5	14.0	13.0	13.5	0.86
12.0	11.0	12.0	12.0	12.5	13.0	13.0	13.0	14.0	0.65
11.0	12.5	13.0	13.0	13.0	13.0	13.0	13.0	14.5	0.80
15.0	14.5	15.0	13.5	13.5	14.0	14.0	13.5	14.0	0.54
15.5	15.0	14.5	13.0	13.0	13.0	10.5	13.0	13.0	1.48
14.0	12.5	14.0	13.5	13.5	13.5	13.5	13.5	14.0	0.52
13.0	13.0	12.0	12.0	13.0	13.0	13.0	13.5	13.5	0.90
11.0	13.0	18.0	14.5	14.0	13.5	13.5	13.5	14.0	1.39
15.0	15.0	16.5	14.0	14.0	14.5	14.0	14.0	14.0	0.65
15.0	15.0	17.0	15.0	15.0	15.0	15.0	15.0	15.0	0.94
14.0	14.0	13.0	13.0	14.0	14.0	14.5	14.0	13.5	0.80
13.5	13.5	14.0	14.0	14.5	15.0	15.0	14.0	14.0	0.51
15.0	14.5	14.5	14.0	14.0	14.0	14.0	14.0	14.0	0.63
13.0	13.0	16.0	13.0	13.0	12.0	11.5	13.0	15.0	1.43
14.5	13.5	13.5	14.0	14.5	13.5	12.5	13.5	13.5	0.50
16.0	14.0	14.5	12.0	14.5	14.0	13.0	12.5	13.5	1.10
12.5	13.0	14.0	12.5	12.0	13.0	13.0	12.0	13.0	0.69
12.0	12.0	12.5	16.0	13.5	13.0	13.0	13.5	14.0	0.99
13.0	13.5	13.0	13.0	12.5	13.0	13.0	13.0	14.0	0.52
12.5	12.5	12.5	10.0	12.0	13.0	13.0	13.0	13.0	0.90
15.0	14.5	16.0	14.0	14.0	14.0	14.0	14.5	14.5	0.99
15.0	14.5	15.5	15.0	16.0	15.0	15.5	15.0	15.0	0.50
13.0	12.5	13.0	13.0	13.0	13.0	13.5	14.0	14.5	0.71
13.0	13.0	13.0	14.5	14.0	14.5	14.5	14.5	14.5	0.73
13.5	13.5	13.5	14.0	14.0	14.0	14.5	14.0	13.0	0.45
15.0	15.0	15.5	15.0	15.0	15.0	15.0	14.5	14.0	0.63
13.5	13.0	13.5	13.0	13.5	14.0	13.5	13.5	13.5	0.37
12.0	12.0	13.0	13.5	12.5	13.0	12.0	13.0	13.0	0.78
16.0	16.5	16.5	14.5	14.5	14.5	15.0	13.0	13.0	1.19
13.0	13.0	13.0	13.0	13.0	12.5	13.0	13.5	13.0	0.61
13.0	13.5	15.0	14.0	14.0	15.0	15.0	13.5	13.5	1.04
14.5	15.0	15.0	15.5	15.5	15.5	14.0	14.0	15.0	0.65

Table E.2. Surface roughness as affected by tillage at Islamabad

T[1]	R[2]	L[3]	Observations 1	2	3	4	5	6	7	8	9	10
C	1	1	9.5	9.0	10.0	9.0	11.0	9.0	11.5	11.0	11.0	9.0
C	1	2	12.5	11.0	11.0	13.0	13.0	15.0	15.5	15.0	15.0	15.0
C	1	3	13.0	11.0	10.0	12.0	14.0	12.5	16.0	15.0	12.5	14.5
C	2	1	12.5	12.0	11.0	12.0	11.5	13.0	14.0	13.5	13.0	13.0
C	2	2	12.0	11.0	12.0	12.0	12.0	12.0	11.0	12.0	11.0	12.5
C	2	3	13.5	14.0	14.0	15.0	15.0	14.0	15.0	15.0	15.0	15.0
C	3	1	14.0	14.0	15.0	15.0	14.0	14.0	14.0	14.0	14.0	13.0
C	3	2	14.0	14.0	13.0	13.5	13.5	13.0	13.0	13.0	14.0	14.0
C	3	3	12.0	12.5	11.5	11.0	11.0	11.5	12.0	10.0	10.0	12.0
R	1	1	10.0	6.0	10.0	7.5	8.5	10.0	4.0	5.0	6.0	8.0
R	1	2	10.5	10.0	10.0	12.5	16.0	12.5	11.5	12.0	12.0	12.0
R	1	3	11.0	10.0	10.0	10.0	10.0	9.0	7.0	8.0	11.0	16.0
R	2	1	10.0	10.0	11.0	11.0	13.0	10.0	10.0	11.0	10.0	10.0
R	2	2	7.5	7.0	8.5	8.0	6.5	8.0	8.0	7.0	7.0	8.0
R	2	3	11.0	11.0	10.0	10.0	9.0	10.0	10.0	13.0	11.0	10.0
R	3	1	12.0	9.0	11.5	10.0	12.0	11.0	16.5	10.0	9.0	10.0
R	3	2	12.0	10.0	12.0	11.0	12.5	11.0	11.0	11.0	10.0	9.5
R	3	3	14.0	14.0	13.0	12.0	12.0	13.0	12.0	12.0	12.0	10.0
D	1	1	12.0	11.0	9.0	10.0	10.0	9.5	8.5	10.0	9.0	13.0
D	1	2	13.0	12.0	11.0	12.0	11.0	10.0	11.0	11.0	10.0	10.0
D	1	3	12.0	10.5	11.0	10.0	10.0	11.5	11.5	11.0	12.0	12.0
D	2	1	14.0	16.0	18.0	17.0	17.0	15.0	13.5	15.0	12.0	12.0
D	2	2	12.0	10.0	9.0	11.0	11.0	11.5	11.0	11.0	11.5	9.0
D	2	3	12.0	11.0	12.0	15.0	13.0	10.0	10.5	10.0	10.0	8.0
D	3	1	10.0	9.0	9.0	9.0	10.5	11.0	11.0	10.5	11.5	12.0
D	3	2	13.0	12.0	12.5	11.0	13.0	19.0	11.5	16.0	15.0	15.5
D	3	3	12.5	10.5	14.0	11.5	14.5	14.5	12.0	14.0	16.0	14.0
M	1	1	13.5	13.0	11.5	12.0	11.0	9.0	12.0	9.0	11.0	12.0
M	1	2	13.0	11.0	11.0	10.0	13.0	11.0	10.0	12.0	11.0	14.0
M	1	3	10.0	8.0	9.0	6.5	11.0	12.0	12.0	10.0	10.0	10.0
M	2	1	12.0	12.0	12.0	11.5	10.5	12.0	12.5	13.0	13.0	12.5
M	2	2	11.0	11.0	11.0	13.0	12.0	13.0	11.0	12.0	14.0	13.0
M	2	3	9.5	9.5	7.0	7.0	9.0	9.0	17.0	9.5	11.0	11.0
M	3	1	9.0	5.0	13.0	11.0	15.0	11.0	11.0	11.0	10.0	11.0
M	3	2	12.5	9.5	11.5	12.0	12.0	13.0	12.0	11.0	12.0	9.0
M	3	3	9.0	9.0	10.0	15.0	12.0	12.0	12.0	10.0	11.0	9.0

[1] Tillage treatments.
[2] Replications.
[3] Locations.
[4] Standard deviation.

11	12	13	14	15	16	17	18	19	SD[4]
11.0	11.5	11.5	10.5	11.5	10.0	15.0	12.0	12.0	1.43
15.0	15.5	11.0	13.0	13.0	13.0	18.0	14.0	14.0	1.76
11.0	13.5	16.0	15.0	14.0	11.0	18.0	13.0	13.0	1.98
14.5	14.5	12.0	14.0	10.5	15.5	14.0	14.0	14.0	1.29
12.5	13.0	13.0	14.0	14.0	13.0	17.0	13.0	14.0	1.37
15.0	14.0	15.0	14.0	15.0	15.0	16.0	13.0	13.0	0.78
13.0	14.0	14.0	14.5	14.5	16.0	12.0	15.0	12.0	0.96
13.0	12.0	12.0	12.0	12.0	13.0	16.0	13.0	13.0	0.94
12.0	11.0	11.0	10.0	11.5	11.0	16.0	12.5	12.0	1.28
10.0	9.0	10.0	11.0	10.0	7.0	12.0	9.0	10.5	2.11
11.5	15.0	14.0	11.0	12.0	16.0	16.0	14.5	10.0	2.01
12.0	14.5	11.0	11.0	10.0	7.0	18.0	10.0	12.0	2.71
10.5	11.0	10.0	10.0	11.0	11.0	15.0	11.0	10.0	1.23
9.0	7.5	8.0	6.0	6.0	9.0	9.0	12.0	18.0	2.61
10.0	10.5	10.0	11.0	11.5	11.5	14.0	10.0	10.0	1.15
11.5	9.0	14.0	13.0	12.0	13.0	19.0	5.0	7.0	3.08
11.0	10.5	17.0	13.0	10.0	10.0	15.0	12.0	12.0	1.80
12.0	11.0	12.0	12.0	11.0	14.0	15.0	10.0	12.0	1.29
11.0	11.0	12.0	11.5	9.5	13.0	17.0	14.0	14.0	2.10
10.5	11.0	12.0	12.5	16.0	15.0	22.0	14.0	13.0	2.77
12.0	13.0	13.0	14.0	14.0	12.5	18.0	15.0	15.0	1.94
11.0	12.0	12.0	15.0	15.0	14.0	17.0	11.0	14.5	2.10
10.0	12.0	12.5	12.0	12.0	14.5	17.0	14.0	14.0	1.91
10.5	9.5	9.0	10.0	9.0	10.0	11.5	11.0	11.5	1.55
12.0	11.0	11.0	10.0	12.0	12.0	16.0	11.0	11.0	1.52
14.0	10.5	14.0	13.5	11.0	14.0	15.0	10.0	12.0	2.16
12.0	13.0	13.0	14.0	10.0	10.0	19.0	14.0	13.0	2.08
12.5	11.0	10.0	12.0	11.5	8.5	16.0	12.5	12.5	1.70
14.5	15.0	16.0	9.0	10.0	10.0	14.5	10.0	13.0	2.02
11.0	9.0	10.0	11.0	10.0	12.0	14.0	9.0	11.0	1.62
13.0	16.5	13.0	14.0	14.0	12.0	16.0	14.0	14.0	1.44
12.5	12.0	13.0	11.5	14.0	12.0	17.5	12.5	12.5	1.48
9.0	9.0	9.0	8.0	11.0	14.0	9.0	11.0	11.0	2.28
12.0	12.0	12.5	15.0	13.5	12.0	19.0	12.5	8.5	2.80
12.0	9.0	8.5	8.5	9.0	11.0	14.0	13.5	10.0	1.69
12.0	10.0	13.0	9.0	10.0	10.0	17.0	10.0	13.0	2.12

Table E.3. Surface roughness prior to tillage at Faisalabad

			Observations									
T[1]	R[2]	L[3]	1	2	3	4	5	6	7	8	9	10
C	1	1	14.0	13.5	14.0	13.5	14.0	14.0	15.0	14.0	14.0	14.0
C	1	2	14.0	14.0	15.0	15.0	13.0	14.0	13.0	15.0	15.0	14.0
C	1	3	14.0	15.0	15.0	14.0	14.0	14.0	14.5	14.0	14.0	14.0
C	2	1	15.0	15.0	15.0	15.0	14.5	14.5	14.5	14.0	14.0	12.5
C	2	2	15.0	14.0	14.0	14.0	14.0	14.0	13.0	14.0	14.0	14.0
C	2	3	13.0	12.0	13.0	14.0	15.0	15.0	15.0	14.0	15.0	14.5
C	3	1	14.5	14.0	14.0	14.0	14.0	14.0	14.5	14.0	14.0	14.0
C	3	2	14.0	14.0	14.0	13.5	13.5	13.0	13.0	14.0	14.0	14.0
C	3	3	14.0	14.0	15.0	14.0	14.0	16.0	15.0	15.5	15.0	15.0
R	1	1	14.0	14.0	15.0	15.5	16.0	15.0	16.5	16.0	16.0	16.0
R	1	2	13.0	13.5	15.0	14.0	15.0	13.0	13.0	13.5	14.0	13.0
R	1	3	14.0	15.0	15.0	15.0	15.0	15.5	15.0	15.5	15.0	15.0
R	2	1	14.5	14.5	14.0	14.0	14.0	13.0	14.0	14.0	14.0	12.0
R	2	2	15.0	14.0	14.0	15.0	14.5	14.5	15.0	15.0	15.0	14.5
R	2	3	15.0	15.0	15.0	15.0	15.0	14.5	15.0	15.0	15.0	14.0
R	3	1	15.0	14.0	15.0	13.0	15.0	15.0	15.0	16.5	15.0	15.0
R	3	2	15.0	15.0	14.5	14.0	14.0	14.0	14.0	14.0	13.5	14.0
R	3	3	15.0	14.0	14.0	15.0	15.0	15.0	15.0	15.0	15.0	14.0
D	1	1	13.0	13.0	14.0	13.0	12.5	14.0	13.0	12.5	13.0	15.0
D	1	2	14.0	15.0	15.0	14.0	14.0	14.0	16.0	15.0	13.0	14.0
D	1	3	15.0	14.0	15.0	14.5	15.0	14.5	14.5	15.0	15.0	14.5
D	2	1	14.0	13.5	13.0	13.5	14.0	14.5	14.0	14.5	14.0	13.0
D	2	2	14.0	14.0	13.0	14.0	15.0	14.0	14.0	14.5	15.0	15.0
D	2	3	14.0	14.0	14.0	14.0	14.0	15.0	14.0	14.5	15.0	15.0
D	3	1	14.0	14.0	13.5	14.0	13.0	13.5	14.0	14.0	13.5	13.0
D	3	2	14.0	14.0	14.0	14.0	14.0	14.5	14.0	14.0	14.0	15.0
D	3	3	14.0	14.5	15.0	15.0	16.0	15.0	16.5	16.0	15.0	15.5
M	1	1	13.0	14.0	14.0	13.5	13.0	14.5	13.0	12.0	13.0	12.0
M	1	2	14.5	14.0	14.0	14.5	14.0	14.5	14.0	15.0	15.0	14.5
M	1	3	14.0	14.0	14.5	14.0	14.0	14.5	14.0	14.5	14.0	15.0
M	2	1	14.0	14.0	15.0	14.0	14.0	14.5	14.0	14.0	15.0	15.0
M	2	2	15.0	15.0	15.0	15.0	16.0	15.0	16.0	16.0	16.0	15.5
M	2	3	15.0	14.0	15.0	16.0	15.0	14.5	14.0	15.0	14.5	14.5
M	3	1	14.0	15.0	15.0	15.0	14.0	15.0	14.0	14.0	15.0	14.0
M	3	2	14.0	14.0	14.0	14.0	15.0	14.0	14.0	13.0	14.0	14.0
M	3	3	13.0	14.0	13.0	15.0	15.0	13.0	15.0	14.0	14.0	14.0

[1] Tillage treatments.
[2] Replications.
[3] Locations.
[4] Standard deviation.

11	12	13	14	15	16	17	18	19	SD[4]
14.0	14.0	14.0	13.0	14.0	14.5	14.0	14.5	14.0	0.40
15.0	15.0	15.0	14.0	15.0	14.0	14.5	12.0	14.0	0.83
14.5	14.0	15.0	14.5	14.5	14.0	15.0	14.0	14.5	0.40
12.5	12.5	13.0	13.0	13.0	14.0	14.0	14.0	14.0	0.87
14.0	14.5	14.5	13.0	14.0	14.0	14.0	14.0	14.0	0.43
14.5	15.0	15.0	16.0	16.0	15.5	15.0	15.5	14.0	1.02
15.0	15.0	14.0	14.0	13.0	15.0	14.0	14.0	15.0	0.50
14.0	14.0	14.0	13.5	13.5	13.5	14.0	14.0	14.0	0.34
14.0	14.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	0.57
15.5	16.0	15.0	15.0	15.0	15.5	14.5	15.0	15.0	0.68
13.0	12.5	12.5	13.0	13.0	14.5	15.0	15.0	14.0	0.86
15.0	15.0	14.0	14.5	14.0	15.0	15.0	14.0	14.0	0.50
12.0	14.0	14.0	14.0	14.0	14.5	14.0	14.0	14.0	0.69
15.0	14.0	15.0	15.0	15.0	14.0	14.5	15.0	14.5	0.40
14.0	14.0	14.0	14.0	14.0	15.0	15.0	14.5	15.0	0.45
16.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	0.66
14.0	14.5	14.5	14.5	14.0	14.0	14.5	15.0	14.0	0.41
14.5	15.0	14.0	14.0	15.0	15.0	15.0	14.5	15.0	0.44
14.0	14.0	14.5	14.0	13.0	14.0	14.0	15.0	14.5	0.76
14.0	14.5	13.0	14.5	13.0	14.5	14.0	14.5	13.0	0.78
15.0	15.0	14.0	14.0	14.0	14.5	15.0	14.0	14.0	0.43
13.0	15.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	0.50
14.5	14.0	15.0	15.0	15.0	13.0	15.0	13.0	13.5	0.71
15.0	15.0	15.0	15.0	15.0	15.0	15.5	14.5	14.5	0.48
13.5	14.0	14.0	13.5	14.0	14.0	15.0	14.5	15.0	0.53
15.0	15.0	15.0	15.0	15.0	15.0	15.0	14.0	14.0	0.48
16.5	14.0	15.0	15.0	15.0	15.0	15.0	15.0	13.5	0.77
13.0	14.0	15.0	15.0	15.0	14.5	15.0	14.5	15.0	0.99
15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	14.5	0.40
15.0	15.0	14.0	12.0	14.0	14.0	14.0	14.5	15.0	0.66
15.5	14.0	15.0	15.0	14.0	14.0	14.5	15.0	15.0	0.51
15.0	15.5	16.0	15.0	14.0	14.5	15.0	14.0	14.0	0.67
15.0	15.0	15.0	15.0	15.5	15.5	15.0	14.0	15.0	0.51
15.0	15.0	15.0	15.0	13.0	13.0	15.0	14.0	15.0	0.68
15.0	15.0	15.0	14.0	14.0	14.0	15.0	13.0	13.0	0.64
16.0	14.0	15.0	15.0	15.0	15.0	14.0	14.0	14.0	0.80

Table E.4. Surface roughness as affected by tillage at Faisalabad

			Observations									
T[1]	R[2]	L[3]	1	2	3	4	5	6	7	8	9	10
C	1	1	10.0	11.0	10.0	9.5	13.0	10.0	12.0	13.0	10.0	12.0
C	1	2	12.0	10.0	11.0	12.0	13.0	13.0	10.0	13.0	12.0	11.0
C	1	3	12.0	8.0	11.0	9.0	10.0	9.0	11.0	10.0	11.0	10.5
C	2	1	10.0	11.0	9.5	8.0	9.0	9.0	11.0	9.0	10.0	7.0
C	2	2	13.0	12.0	9.0	13.0	12.0	8.5	1.0	9.5	14.0	13.0
C	2	3	11.0	11.0	9.0	15.0	11.0	11.0	10.0	8.0	11.0	9.0
C	3	1	12.5	12.5	12.0	19.0	18.5	17.0	16.0	17.0	16.0	14.0
C	3	2	11.0	11.0	9.0	10.0	10.0	8.0	8.5	10.0	8.0	10.0
C	3	3	13.0	10.0	12.0	9.0	11.0	12.0	12.0	11.0	10.0	13.0
R	1	1	10.0	8.0	9.0	10.0	9.0	10.0	12.0	11.0	13.0	11.0
R	1	2	9.0	8.0	9.0	10.5	8.0	10.0	8.5	10.0	9.0	8.0
R	1	3	12.0	12.5	11.5	9.0	11.0	10.5	10.5	10.5	13.0	11.0
R	2	1	10.0	8.0	12.5	11.0	14.0	11.0	12.5	8.0	10.0	11.0
R	2	2	13.0	11.0	12.0	12.0	9.0	9.0	11.0	9.0	9.0	9.0
R	2	3	10.0	7.0	8.0	13.0	9.0	8.5	8.0	7.5	9.0	8.5
R	3	1	7.0	8.0	8.0	16.0	9.0	9.0	9.0	7.5	7.0	7.0
R	3	2	9.0	9.0	11.0	9.5	11.0	11.0	10.0	9.0	8.0	8.0
R	3	3	11.0	9.5	9.0	9.0	15.5	11.0	8.0	10.5	10.0	10.0
D	1	1	14.5	13.0	10.0	10.0	10.0	12.0	11.0	12.0	11.0	12.0
D	1	2	11.5	12.5	13.5	13.0	16.0	14.0	12.0	12.0	12.5	10.5
D	1	3	11.0	10.0	12.0	12.0	10.0	9.0	10.0	10.0	10.0	11.0
D	2	1	12.0	13.0	12.0	11.0	11.0	16.0	12.0	13.0	12.0	11.0
D	2	2	12.0	10.0	14.0	13.0	13.5	9.5	11.0	10.0	10.0	12.0
D	2	3	13.0	11.0	12.0	14.0	12.0	11.0	12.0	10.0	11.0	11.0
D	3	1	13.0	15.0	12.0	15.0	12.0	12.0	14.0	14.0	14.0	13.0
D	3	2	11.0	12.5	13.0	12.0	14.0	14.0	13.0	15.0	14.0	13.0
D	3	3	14.5	14.0	14.0	12.0	13.0	15.0	14.0	14.0	12.0	14.0
M	1	1	12.0	10.0	12.0	15.0	14.0	13.0	13.0	14.0	15.0	15.0
M	1	2	10.5	9.5	8.0	8.0	9.0	9.0	9.0	8.0	10.5	10.0
M	1	3	12.0	12.0	11.0	11.0	9.5	11.0	10.0	10.0	10.0	10.0
M	2	1	13.0	13.5	13.5	13.0	13.0	12.0	11.0	11.5	11.5	12.0
M	2	2	13.0	12.0	13.0	12.0	14.0	14.0	13.0	15.0	14.0	13.0
M	2	3	13.0	9.0	10.0	9.0	10.0	12.0	12.0	13.0	13.0	11.0
M	3	1	15.0	15.0	12.5	16.0	13.0	15.0	15.0	14.0	12.0	13.0
M	3	2	14.0	13.0	12.0	14.0	13.0	11.5	13.0	10.0	12.0	12.0
M	3	3	13.0	13.0	10.0	13.0	11.0	12.0	2.0	13.0	12.0	12.0

[1] Tillage treatments.
[2] Replications.
[3] Locations.
[4] Standard deviation.

11	12	13	14	15	16	17	18	19	SD[4]
13.0	12.0	12.0	11.0	11.0	9.0	9.0	8.0	13.0	1.51
12.5	12.0	11.0	12.0	11.0	11.0	10.0	13.0	14.0	1.13
9.0	11.0	12.5	8.0	11.5	7.0	13.0	13.0	12.0	1.70
10.0	9.0	9.0	9.0	7.0	9.0	9.5	9.5	10.0	1.04
13.0	12.0	9.5	7.5	10.0	9.0	10.0	10.0	13.0	2.91
9.0	10.0	10.0	10.5	11.0	9.0	10.0	7.0	10.0	1.59
15.0	14.0	17.0	19.0	14.0	17.0	17.0	14.0	14.0	2.14
10.0	9.0	10.0	6.0	9.0	10.0	11.0	9.0	9.0	1.20
11.0	13.0	12.0	11.5	11.0	11.5	12.0	9.0	13.0	1.22
10.0	14.0	13.0	10.0	9.0	13.0	11.0	9.5	10.0	1.16
11.0	10.0	10.0	9.0	11.0	8.0	9.0	6.0	10.0	1.21
15.0	15.0	10.0	8.0	12.0	11.0	9.0	8.0	12.5	1.92
11.0	9.0	11.0	11.5	10.0	11.0	10.0	11.0	10.0	1.42
10.0	11.0	9.0	12.0	10.0	8.0	11.0	9.5	11.0	1.35
9.0	8.0	8.0	7.0	10.0	9.0	8.0	10.0	9.0	1.33
8.0	9.0	9.0	10.0	10.5	11.0	8.5	9.0	8.0	1.98
12.5	12.0	9.0	10.0	10.0	11.0	12.0	12.0	8.0	1.42
8.5	10.5	10.0	9.0	9.0	8.5	10.0	9.0	11.0	1.58
16.0	14.0	14.0	13.0	12.0	12.0	12.0	12.0	15.0	1.66
10.0	11.0	10.0	13.0	13.0	11.0	10.0	13.0	13.0	1.51
10.0	10.0	9.0	10.0	12.0	12.0	13.0	9.0	13.0	1.26
12.0	13.0	12.0	11.0	11.0	11.0	13.0	11.5	12.0	1.17
11.0	11.0	11.5	11.0	12.0	11.0	11.0	12.0	12.0	1.17
12.5	12.0	13.0	13.0	13.0	12.5	10.0	12.0	12.5	1.04
15.0	14.0	15.0	11.0	13.0	12.0	12.0	13.0	12.0	1.24
14.0	13.0	11.0	12.0	13.0	11.0	11.5	14.0	11.0	1.22
14.0	14.0	14.0	14.0	13.0	14.0	14.0	15.0	15.0	0.82
14.0	10.0	11.0	11.0	12.0	12.5	12.0	10.0	12.0	1.63
9.0	11.0	6.5	9.0	9.0	8.0	8.0	10.0	12.5	1.33
12.0	12.0	12.0	13.0	12.0	12.0	10.0	13.0	13.0	1.12
12.0	11.0	13.0	13.0	11.5	12.5	12.0	12.0	13.0	0.78
14.0	13.0	11.0	12.0	13.0	11.0	11.5	14.0	11.0	1.16
12.0	11.0	11.0	16.0	12.0	10.5	12.0	12.0	11.0	1.58
14.5	13.0	12.0	13.0	11.0	14.0	14.0	13.0	14.0	1.25
12.0	12.0	12.5	12.0	12.5	10.0	11.0	10.0	11.0	1.16
13.0	12.0	12.0	13.0	14.0	12.5	12.5	12.0	14.0	2.51

Table E.5. Surface roughness prior to tillage at Pirsabaq

T[1]	R[2]	L[3]	Observations 1	2	3	4	5	6	7	8	9	10
C	1	1	15.0	14.0	14.0	14.0	15.0	15.0	14.0	15.5	15.0	14.0
C	1	2	15.5	15.0	16.0	15.0	13.5	15.0	14.5	14.5	13.0	13.5
C	1	3	13.0	15.0	15.0	16.0	13.5	14.5	12.0	16.0	18.0	16.0
C	2	1	15.0	14.0	14.5	14.5	14.0	14.5	14.0	14.5	14.0	13.0
C	2	2	15.0	15.5	15.0	14.5	13.5	13.0	14.0	14.0	15.0	14.0
C	2	3	14.0	14.0	14.5	15.0	15.0	16.0	14.0	14.5	17.0	13.0
C	3	1	14.5	14.0	14.5	14.5	14.0	15.0	15.0	15.0	15.0	15.0
C	3	2	14.5	14.5	14.0	14.5	14.0	12.0	12.5	13.5	13.0	13.0
C	3	3	14.5	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
R	1	1	15.0	15.0	15.0	15.0	15.0	15.5	16.0	16.0	16.0	15.0
R	1	2	14.5	13.5	14.0	14.0	14.0	14.0	14.0	14.0	15.0	14.0
R	1	3	15.0	14.0	15.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
R	2	1	15.0	14.0	14.0	13.0	13.0	14.0	15.0	15.0	14.0	14.0
R	2	2	16.0	15.0	15.0	14.0	13.0	14.0	16.0	16.0	15.0	15.0
R	2	3	15.0	14.0	14.0	15.0	15.0	16.0	15.0	15.0	16.0	15.5
R	3	1	16.0	16.5	14.0	14.0	14.0	15.5	13.0	13.5	16.0	16.0
R	3	2	13.0	13.0	13.5	14.0	13.0	15.0	15.0	14.0	14.0	13.5
R	3	3	15.0	15.0	14.5	17.0	16.0	16.5	14.0	14.0	14.5	15.0
D	1	1	14.5	14.0	13.5	14.0	14.0	14.0	14.0	15.0	15.0	14.0
D	1	2	14.0	14.0	14.0	14.0	13.5	13.0	12.0	13.0	13.0	13.0
D	1	3	15.0	14.0	14.0	14.0	14.0	15.0	14.5	14.5	14.0	14.0
D	2	1	16.0	16.0	16.0	15.0	15.0	15.0	14.0	14.0	15.5	15.0
D	2	2	16.0	15.0	16.0	15.5	15.0	15.5	16.0	15.5	16.0	16.0
D	2	3	15.0	15.0	15.0	15.0	15.0	14.5	16.0	16.0	15.5	14.5
D	3	1	13.5	14.0	14.0	14.0	14.5	15.0	13.0	13.0	16.0	18.0
D	3	2	15.0	15.5	15.0	17.0	16.0	13.0	12.5	16.0	15.0	14.0
D	3	3	14.0	14.0	16.0	13.0	13.0	15.5	13.0	14.0	16.0	15.0
M	1	1	16.0	16.5	14.0	14.5	13.0	15.0	15.0	15.5	17.0	12.0
M	1	2	13.0	14.0	14.0	15.0	16.5	17.0	12.0	14.0	14.0	13.0
M	1	3	15.0	15.0	14.0	14.5	13.0	13.5	15.0	15.0	16.0	16.0
M	2	1	13.5	15.0	15.0	14.0	14.5	14.0	13.0	16.0	15.0	17.5
M	2	2	14.0	14.5	16.0	17.0	18.5	15.0	13.0	14.5	13.0	13.0
M	2	3	16.0	15.5	14.0	13.0	13.0	15.5	14.0	14.0	14.5	12.5
M	3	1	14.5	14.0	14.0	13.5	13.5	14.0	14.0	14.0	14.0	14.0
M	3	2	14.5	13.0	13.5	13.0	12.5	13.0	12.0	12.5	13.0	13.0
M	3	3	14.0	13.5	13.0	13.0	13.5	13.5	13.0	13.5	13.0	13.5

[1] Tillage treatments.
[2] Replications.
[3] Locations.
[4] Standard deviation.

11	12	13	14	15	16	17	18	19	SD[4]
14.5	14.5	15.0	15.0	15.0	15.0	18.0	15.0	15.0	0.87
14.0	13.5	13.5	14.0	13.0	14.0	19.5	12.0	12.5	1.58
14.0	14.0	15.0	15.5	13.0	15.5	16.0	16.5	13.0	1.46
14.0	14.0	13.5	14.0	14.0	14.0	15.5	14.5	15.0	0.55
14.0	14.0	13.5	13.0	13.0	14.0	14.5	14.5	14.0	0.70
14.0	14.5	13.5	13.0	14.0	14.0	15.5	14.5	15.0	0.95
15.0	14.0	14.5	14.0	14.0	14.0	14.0	14.0	14.5	0.43
13.5	13.5	14.0	14.0	14.0	14.0	13.0	14.0	14.5	0.69
14.0	14.0	15.0	15.0	14.0	14.5	14.0	14.0	15.5	0.44
15.0	15.0	15.0	15.0	14.0	14.0	14.0	14.0	15.0	0.62
14.0	14.0	14.0	15.0	14.0	14.0	14.0	14.0	14.5	0.36
15.0	15.0	15.0	14.5	14.5	14.0	14.0	14.0	15.5	0.50
14.0	15.0	14.0	15.0	14.0	14.0	18.0	14.0	14.0	1.04
14.0	16.0	15.0	16.0	15.0	14.0	18.0	14.0	15.0	1.10
16.0	15.0	14.0	16.0	15.0	17.0	18.0	15.0	16.0	0.98
17.0	14.0	15.5	13.5	14.0	14.0	18.0	14.5	13.5	1.37
16.0	14.0	14.5	17.0	15.0	14.0	14.0	14.5	14.0	0.99
15.0	16.0	16.0	13.0	13.0	14.5	13.0	15.5	14.0	1.14
14.0	14.0	14.0	14.5	14.5	14.5	14.5	14.5	14.5	0.38
14.0	14.0	14.0	14.0	14.0	14.0	14.5	14.5	15.0	0.68
14.0	14.0	14.0	14.0	13.0	13.0	13.0	13.5	16.0	0.71
14.0	14.0	13.5	14.0	14.0	14.0	17.0	12.0	12.5	1.21
16.5	15.5	15.5	16.0	16.0	15.5	19.0	16.0	16.0	0.82
13.0	14.5	13.0	14.5	15.0	11.5	15.0	14.0	16.0	1.10
11.0	13.5	14.0	14.0	15.0	13.5	14.5	16.0	13.0	1.43
14.0	14.5	16.0	12.5	14.0	15.0	15.5	17.5	13.0	1.39
17.0	13.5	15.0	12.0	12.5	11.0	14.5	15.0	16.0	1.52
13.5	14.0	14.0	15.0	15.5	13.0	17.0	18.0	12.0	1.64
13.5	14.0	14.0	15.5	16.0	12.0	13.0	14.0	14.0	1.33
12.0	14.0	14.0	18.0	15.0	15.0	14.0	14.5	13.0	1.28
12.0	15.5	14.0	14.0	16.0	14.5	13.0	16.5	14.0	1.30
15.5	16.0	17.0	15.0	15.5	12.5	16.0	13.0	16.0	1.60
13.0	13.5	14.0	14.0	15.5	17.5	12.5	14.0	15.0	1.27
15.0	13.0	14.0	14.5	14.0	14.0	14.0	13.5	16.0	0.61
13.0	12.5	11.5	12.0	12.0	12.5	13.0	13.0	14.5	0.74
14.0	13.5	14.0	14.0	14.5	15.5	15.0	14.5	15.0	0.72

Table E.6. Surface roughness as affected by tillage at Pirsabaq

T[1]	R[2]	L[3]	Observations 1	2	3	4	5	6	7	8	9	10
C	1	1	9.0	11.0	12.0	11.5	10.5	11.0	13.0	13.0	13.0	13.0
C	1	2	13.0	11.0	10.0	11.0	11.0	14.0	11.0	11.0	10.5	10.0
C	1	3	11.0	9.0	10.0	9.0	9.0	8.0	7.0	7.0	8.0	8.0
C	2	1	9.0	9.0	11.0	9.0	10.0	9.5	10.5	10.0	12.0	10.0
C	2	2	13.0	10.0	9.0	10.0	11.0	9.0	11.0	11.0	11.0	11.0
C	2	3	11.0	13.0	12.0	11.5	12.0	10.0	9.5	9.5	11.0	11.0
C	3	1	12.0	12.0	11.0	10.5	10.5	11.0	11.0	10.5	13.0	12.0
C	3	2	10.0	10.0	9.0	10.0	11.0	11.0	9.0	10.0	10.0	11.0
C	3	3	10.0	8.0	8.0	6.0	8.0	7.0	10.0	12.0	10.0	12.0
R	1	1	11.5	11.0	11.0	10.0	8.5	12.0	16.0	10.0	11.5	11.0
R	1	2	9.0	9.5	9.0	10.0	10.0	8.5	8.0	7.0	9.0	8.0
R	1	3	9.0	9.0	7.0	9.0	10.0	10.0	10.5	10.0	10.5	8.0
R	2	1	10.0	12.0	11.0	11.0	11.0	9.0	10.0	9.0	7.0	8.5
R	2	2	10.0	9.0	9.0	9.0	9.0	7.5	10.0	9.0	7.0	8.0
R	2	3	11.0	7.5	9.0	7.0	10.0	10.0	10.0	11.0	10.0	11.0
R	3	1	11.0	10.0	10.0	10.0	10.0	10.0	12.0	10.0	10.0	9.0
R	3	2	12.0	10.0	11.0	12.0	10.0	8.0	9.0	11.0	10.0	8.0
R	3	3	12.0	10.0	10.0	11.0	10.0	10.0	10.5	10.5	11.0	12.0
D	1	1	12.0	7.0	7.5	5.0	7.0	9.0	11.0	9.0	11.0	8.0
D	1	2	10.5	10.0	9.0	8.0	7.0	11.0	10.0	10.0	12.0	9.0
D	1	3	8.0	7.0	6.0	6.0	8.0	12.0	15.0	9.0	10.0	8.0
D	2	1	10.0	10.0	11.0	13.0	9.0	11.0	11.0	10.0	10.0	10.5
D	2	2	7.0	6.0	9.0	8.0	5.0	5.0	10.0	8.0	10.0	7.0
D	2	3	9.0	8.0	8.0	9.0	9.5	9.0	9.0	9.0	11.5	7.0
D	3	1	12.0	11.0	9.0	11.5	9.0	9.5	10.0	8.0	8.0	8.0
D	3	2	10.0	11.0	11.0	11.0	11.0	11.5	12.0	15.0	15.0	13.0
D	3	3	9.0	9.0	9.0	11.0	9.5	8.5	8.0	8.0	7.0	7.0
M	1	1	13.5	10.0	12.0	13.5	13.0	16.0	11.5	12.0	16.0	11.0
M	1	2	12.5	11.0	12.0	11.0	11.0	10.0	11.0	11.0	10.0	13.0
M	1	3	10.0	13.0	12.0	12.0	14.0	13.0	8.0	11.0	12.0	12.0
M	2	1	13.0	15.0	15.5	17.0	15.0	14.5	15.0	14.5	13.5	10.0
M	2	2	14.5	14.5	15.0	13.0	8.5	12.5	13.0	12.0	13.0	12.0
M	2	3	15.0	14.0	14.0	14.0	15.0	15.0	14.0	15.0	13.0	14.5
M	3	1	10.0	9.0	11.0	12.0	13.0	13.0	14.0	12.0	11.0	11.0
M	3	2	12.0	9.0	12.0	8.0	9.5	12.0	13.0	13.0	14.0	13.0
M	3	3	13.0	11.0	11.0	11.0	11.0	12.0	15.0	10.0	14.0	11.0

[1] Tillage treatments.
[2] Replications.
[3] Locations.
[4] Standard deviation.

11	12	13	14	15	16	17	18	19	SD[4]
12.0	10.0	10.0	11.0	11.5	11.0	12.5	10.0	11.0	1.16
10.5	12.0	10.0	10.5	10.0	11.0	10.0	11.0	12.0	1.04
10.0	9.0	10.0	10.0	10.5	11.0	11.0	12.0	8.0	1.40
10.0	10.0	9.0	11.0	10.0	8.0	10.0	12.0	11.0	1.01
14.0	12.0	9.5	10.0	10.5	12.0	12.0	11.5	14.0	1.42
10.0	9.0	9.5	9.0	9.5	13.0	10.0	11.0	13.5	1.37
13.0	13.0	13.0	12.0	12.0	14.0	12.5	13.0	14.0	1.10
12.0	11.0	11.0	10.0	10.0	11.0	11.0	10.0	11.0	0.75
7.0	11.0	10.0	11.0	12.0	6.0	5.0	6.0	11.0	2.26
10.0	11.0	11.0	11.5	10.0	10.0	10.0	10.0	12.0	1.47
10.0	9.0	8.5	8.0	9.0	8.0	10.0	8.0	10.0	0.87
10.0	8.5	8.0	9.0	8.0	9.0	9.0	10.0	11.0	1.02
9.0	8.0	8.5	9.0	8.0	8.0	9.0	9.0	10.0	1.25
8.0	9.0	9.0	10.0	9.0	9.0	11.0	7.0	10.0	1.03
10.0	9.0	9.0	14.0	11.0	11.0	12.0	11.0	13.0	1.64
9.0	9.0	12.0	7.0	10.0	11.5	9.5	11.0	10.0	1.13
9.0	9.5	9.5	8.5	8.0	10.0	9.0	11.0	10.0	1.21
11.0	12.0	11.0	11.0	10.0	10.0	11.0	13.0	11.0	0.84
10.0	9.0	11.0	11.0	9.0	9.0	10.0	10.0	10.0	1.70
6.0	9.0	9.0	10.0	9.0	9.0	11.0	8.5	8.0	1.40
11.0	11.0	11.0	7.0	11.0	15.0	10.0	10.0	7.5	2.56
10.5	11.0	5.0	7.0	9.0	6.0	9.0	10.0	10.0	1.83
5.0	8.0	7.0	8.0	7.0	8.0	8.0	9.0	10.0	1.56
9.0	10.0	10.0	9.0	9.0	9.0	9.0	10.5	10.5	0.98
9.0	10.0	8.0	8.0	13.0	11.0	10.0	10.5	10.5	1.45
12.0	11.0	11.0	10.0	10.5	10.0	12.0	11.0	12.0	1.40
7.0	6.0	6.0	7.0	8.0	8.0	9.0	9.0	10.0	1.29
11.0	16.5	17.0	12.0	13.0	9.0	11.0	13.5	13.0	2.16
14.0	15.0	14.5	11.0	15.5	14.0	14.0	10.0	12.0	1.74
9.0	10.0	15.0	14.0	14.0	13.5	13.0	8.0	13.0	2.01
12.0	12.5	12.5	13.5	13.5	11.0	11.0	12.0	13.0	1.72
11.0	12.0	11.0	10.0	11.0	10.5	11.5	13.5	14.0	1.65
14.0	12.5	13.5	11.0	11.0	10.5	12.0	14.0	13.5	1.39
10.0	9.0	10.0	9.0	9.0	9.0	9.0	10.0	10.5	1.53
11.0	11.0	12.5	11.5	13.0	12.0	13.0	13.0	14.0	1.58
10.0	11.0	11.5	10.0	11.0	10.0	10.0	10.0	11.0	1.36

Table E.7. Analysis of variance of surface roughness

Source	DF	Islamabad	Faisalabad	Pirsabaq
		F-values		
Before Tillage				
Trt. plts	3	3.05*	< 1	< 1
Rep(plt) Error (a)	8	--	--	--
Error (b)	24	--	--	--
Corr. Total	35			
After Tillage				
Trt.	3	3.92**	1.82	4.39***
Rep(trt) Error (a)	8	--	--	--
Error (b)	24	--	--	--
Corr. Total	35			

*Significant at 0.10 probability level.
**Significant at 0.05 probability level.
***Significant at 0.01 probability level.

APPENDIX F: TILLAGE DEPTH DATA

Table F.1. Implement penetration measured as tillage depth at Islamabad

Trt.	Rep.	Loc.	Tillage Depth (cm) 1	2	3	Avg.*
C	1	1	11.43	8.89	7.62	9.31
C	1	2	7.62	9.53	8.26	8.47
C	1	3	8.89	8.89	7.62	8.47
C	2	1	12.07	9.53	11.43	11.01
C	2	2	11.43	10.16	7.62	9.74
C	2	3	8.89	12.70	6.35	9.31
C	3	1	0.00	0.00	0.00	0.00
C	3	2	0.00	0.00	0.00	0.00
C	3	3	0.00	0.00	0.00	0.00
R	1	1	10.16	11.43	10.16	10.58
R	1	2	11.43	10.80	10.16	10.80
R	1	3	11.43	11.43	12.70	11.85
R	2	1	0.00	0.00	0.00	0.00
R	2	2	0.00	0.00	0.00	0.00
R	2	3	0.00	0.00	0.00	0.00
R	3	1	10.16	11.43	11.43	11.01
R	3	2	8.89	8.89	10.16	9.31
R	3	3	11.43	12.07	12.07	11.85
D	1	1	5.08	6.35	6.35	5.93
D	1	2	6.35	7.62	7.62	7.20
D	1	3	6.35	6.35	7.62	6.77
D	2	1	6.35	8.26	5.72	6.77
D	2	2	5.08	2.54	3.81	3.81
D	2	3	5.08	5.08	5.08	5.08
D	3	1	7.62	10.16	6.35	8.04
D	3	2	8.26	6.35	7.62	7.41
D	3	3	5.08	6.35	7.62	6.35
M	1	1	22.86	22.86	25.40	23.71
M	1	2	20.32	22.86	22.86	22.01
M	1	3	17.78	19.05	19.05	18.63
M	2	1	21.59	22.86	21.59	22.01
M	2	2	21.59	20.32	20.32	20.74
M	2	3	20.32	21.59	21.59	21.17
M	3	1	20.32	17.78	17.78	18.63
M	3	2	17.78	20.32	17.78	18.63
M	3	3	17.78	16.51	16.51	16.93

* Average of three pins position, inserted to measure tillage depth at one point.

Table F.2. Implement penetration measured as tillage depth at Faisalabad

Trt.	Rep.	Loc.	Tillage Depth (cm) 1	2	3	Avg.*
C	1	1	7.62	5.08	6.35	6.35
C	1	2	11.43	7.62	5.72	8.26
C	1	3	12.07	6.99	8.26	9.10
C	2	1	10.80	12.07	7.62	10.16
C	2	2	6.99	8.89	6.99	7.62
C	2	3	8.26	10.16	8.26	8.89
C	3	1	6.99	10.16	8.89	8.68
C	3	2	7.62	6.35	12.70	8.89
C	3	3	8.89	10.16	9.53	9.53
R	1	1	11.43	11.43	11.43	11.43
R	1	2	12.70	12.70	12.70	12.70
R	1	3	10.16	11.43	11.43	11.01
R	2	1	10.80	10.16	10.80	10.58
R	2	2	12.07	12.70	12.70	12.49
R	2	3	10.80	11.43	12.70	11.64
R	3	1	10.16	10.16	10.16	10.16
R	3	2	11.43	11.43	11.43	11.43
R	3	3	11.43	11.43	12.70	11.85
D	1	1	5.08	5.08	4.45	4.87
D	1	2	4.45	5.08	9.53	6.35
D	1	3	8.26	7.62	5.08	6.99
D	2	1	8.26	7.62	6.35	7.41
D	2	2	7.62	6.35	5.08	6.35
D	2	3	8.89	9.53	9.53	9.31
D	3	1	8.89	6.35	6.99	7.41
D	3	2	7.62	5.08	9.53	7.41
D	3	3	6.99	7.62	8.26	7.62
M	1	1	20.32	18.42	18.42	19.05
M	1	2	22.23	21.59	20.96	21.59
M	1	3	19.69	18.42	19.05	19.05
M	2	1	19.05	17.15	18.42	18.20
M	2	2	17.15	12.70	11.43	13.76
M	2	3	18.42	15.24	15.88	16.51
M	3	1	21.59	18.42	21.59	20.53
M	3	2	21.59	20.96	20.96	21.17
M	3	3	22.23	23.50	24.13	23.28

* Average of three pins position, inserted to measure tillage depth at one point.

Table F.3. Implement penetration measured as tillage depth at Pirsabaq

Trt.	Rep.	Loc.	Tillage Depth (cm) 1	2	3	Avg.*
C	1	1	11.43	7.62	6.99	8.68
C	1	2	10.80	6.99	10.16	9.31
C	1	3	11.43	7.62	11.43	10.16
C	2	1	11.43	11.43	11.43	11.43
C	2	2	12.70	7.62	10.16	10.16
C	2	3	11.43	6.35	12.70	10.16
C	3	1	7.62	10.16	10.16	0.00
C	3	2	6.35	6.35	10.80	7.83
C	3	3	10.16	6.35	11.43	9.31
R	1	1	11.43	11.43	11.43	11.43
R	1	2	8.89	10.16	6.99	8.68
R	1	3	8.26	8.26	8.89	8.47
R	2	1	3.81	3.81	7.62	5.08
R	2	2	5.08	9.53	7.62	7.41
R	2	3	5.72	4.45	4.45	4.87
R	3	1	11.43	11.43	12.70	11.85
R	3	2	11.43	12.07	11.43	11.64
R	3	3	11.43	10.80	10.80	11.01
D	1	1	6.35	6.60	5.08	6.01
D	1	2	6.35	6.35	7.62	6.77
D	1	3	4.45	5.08	5.08	4.87
D	2	1	5.08	3.81	4.57	4.49
D	2	2	4.45	6.35	5.08	5.29
D	2	3	6.35	5.08	5.08	5.50
D	3	1	7.62	4.45	7.62	6.56
D	3	2	8.26	5.08	8.89	7.41
D	3	3	6.35	4.45	6.35	5.72
M	1	1	19.05	20.96	22.86	20.96
M	1	2	16.51	18.42	19.05	17.99
M	1	3	15.24	17.15	19.05	17.15
M	2	1	23.50	21.59	22.23	22.44
M	2	2	20.32	19.05	19.05	19.47
M	2	3	17.78	19.05	17.78	18.20
M	3	1	22.86	24.13	20.32	22.44
M	3	2	21.59	22.23	17.78	20.53
M	3	3	19.05	21.59	16.51	19.05

* Average of three pins position, inserted to measure tillage depth at one point.

Table F.4. Analysis of variance of tillage depth

Source	DF	Islamabad	Faisalabad	Pirsabaq
		F-values		
Trt.	3	60.84***	38.40***	40.67***
Rep(trt) Error (a)	8	--	--	--
Error (b)	24	--	--	--
Corr. Total	35			

*Significant at 0.10 probability level.
**Significant at 0.05 probability level.
***Significant at 0.01 probability level.

APPENDIX G: AGGREGATE SIZE DATA

Table G.1. Aggregate size data as affected by tillage at Islamabad

		Seive size (cm)								
T[1]	R[2]	Pan	10	20	30	40	50	60	70	MWD[1]
C	1	4.08	0.63	0.35	0.27	0.06	0.00	0.15	0.00	10.88
C	2	1.51	0.46	0.27	0.18	0.18	0.07	0.00	0.00	14.89
C	3	1.73	0.33	0.11	0.10	0.03	0.00	0.00	0.00	9.18
R	1	2.28	0.56	0.23	0.12	0.13	0.16	0.10	0.00	14.19
R	2	1.97	0.31	0.25	0.15	0.00	0.00	0.00	0.00	9.73
R	3	5.39	1.38	0.70	0.48	0.24	0.19	0.00	0.27	14.24
D	1	2.27	0.53	0.30	0.05	0.19	0.00	0.00	0.00	11.11
D	2	3.01	0.63	0.37	0.25	0.10	0.06	0.00	0.00	11.34
D	3	3.72	0.56	0.32	0.18	0.05	0.28	0.00	0.00	11.55
M	1	2.29	0.78	0.53	0.47	0.49	0.22	0.00	0.00	18.19
M	2	2.55	0.59	0.37	0.26	0.16	0.08	0.00	0.34	17.75
M	3	2.76	1.08	0.93	0.74	0.41	0.20	0.72	0.14	23.80

1 Tillage treatments.
2 Replications.
3 Mean weight diameter (mm).

Table G.2. Aggregate size data as affected by tillage at Faisalabad

		Seive size (cm)								
T[1]	R[2]	Pan	10	20	30	40	50	60	70	MWD[1]
C	1	4.29	0.21	0.36	0.33	0.00	0.00	0.00	0.00	8.70
C	2	3.69	0.66	0.27	0.22	0.12	0.00	0.00	0.00	9.72
C	3	4.98	0.68	0.50	0.32	0.27	0.27	0.00	0.00	12.22
R	1	3.33	0.94	0.74	0.57	0.52	0.35	0.00	0.00	17.34
R	2	4.63	0.88	0.40	0.13	0.12	0.00	0.00	0.16	10.86
R	3	5.08	1.35	0.93	0.82	0.76	0.21	0.00	0.86	20.74
D	1	3.16	0.62	0.50	0.08	0.22	0.11	0.47	0.00	16.91
D	2	3.33	0.71	0.31	0.39	0.15	0.00	0.00	0.00	11.35
D	3	2.25	0.41	0.26	0.07	0.02	0.19	0.00	0.00	11.77
M	1	4.54	0.75	0.43	0.34	0.17	0.00	0.00	0.65	16.44
M	2	6.70	1.18	0.63	0.23	0.27	0.00	0.00	0.00	9.68
M	3	4.67	0.63	0.28	0.20	0.15	0.15	0.24	0.14	13.62

1 Tillage treatments.
2 Replications.
3 Mean weight diameter (mm).

Table G.3. Aggregate size data as affected by tillage at Pirsabaq

T[1]	R[2]	Seive size (cm)								MWD[1]
		Pan	10	20	30	40	50	60	70	
C	1	2.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00
C	2	5.39	0.48	0.17	0.19	0.06	0.00	0.00	0.00	7.56
C	3	3.78	0.54	0.28	0.17	0.10	0.00	0.00	0.20	11.70
R	1	4.53	1.17	0.53	0.26	0.12	0.00	0.00	0.00	10.30
R	2	2.18	0.44	0.20	0.06	0.00	0.00	0.00	0.00	8.54
R	3	4.25	0.74	0.45	0.04	0.00	0.00	0.00	0.00	8.22
D	1	5.42	1.22	0.61	0.33	0.24	0.09	0.13	0.00	12.03
D	2	4.98	1.15	0.73	0.13	0.00	0.13	0.00	0.24	12.22
D	3	4.87	0.70	0.38	0.03	0.19	0.00	0.00	0.00	8.71
M	1	5.84	0.58	0.56	0.21	0.11	0.13	0.00	0.00	9.57
M	2	6.10	0.87	0.51	0.42	0.00	0.25	0.21	0.00	11.77
M	3	5.13	0.63	0.21	0.12	0.00	0.00	0.00	0.00	7.31

1 Tillage treatments.
2 Replications.
3 Mean weight diameter (mm).

Table G.4. Analysis of variance of mean weight diameter

Source	DF	Islamabad	Faisalabad	Pirsabaq
		F-values		
Trt.	3	7.36***	1.50	< 1
Error	8	--	--	--
Corr. Total	11			

*Significant at 0.10 probability level.
**Significant at 0.05 probability level.
***Significant at 0.01 probability level.

APPENDIX H: EMERGENCE COUNT DATA

Table H.1. Emergence count data under different tillage treatments at Islamabad

			No of Plants/Sq.m.				
			Days after planting				
Trt.	Rep.	Rows	7	8	9	10	11
C	1	1	185	215	208	238	282
C	1	2	209	243	214	241	263
C	1	3	216	285	361	373	377
C	2	1	206	218	228	265	251
C	2	2	160	182	140	152	163
C	2	3	203	210	209	242	277
C	3	1	.	.	.	.	.
C	3	2	.	.	.	.	.
C	3	3	.	.	.	.	.
R	1	1	242	285	232	238	288
R	1	2	260	295	290	348	377
R	1	3	240	296	285	305	311
R	2	1	349	388	380	384	397
R	2	2	276	320	355	359	388
R	2	3	327	366	256	365	373
R	3	1	367	410	397	400	411
R	3	2	310	375	410	450	461
R	3	3	190	215	289	193	196
D	1	1	263	290	239	248	312
D	1	2	232	254	210	250	253
D	1	3	288	293	267	278	288
D	2	1	75	80	84	150	172
D	2	2	0	1	5	11	13
D	2	3	126	136	159	165	167
D	3	1	147	220	207	272	277
D	3	2	175	200	235	265	281
D	3	3	155	176	199	213	245
M	1	1	343	378	388	398	411
M	1	2	353	376	380	388	391
M	1	3	253	311	281	336	333
M	2	1	187	223	235	240	242
M	2	2	137	163	172	185	187
M	2	3	153	210	216	223	217
M	3	1	198	216	194	203	221
M	3	2	235	285	290	350	352
M	3	3	242	280	224	245	242

12	13	14	15	16	17	18	19
299	218	230	271	267	271	283	271
276	240	260	260	265	263	262	258
375	379	343	355	357	376	359	357
245	198	225	228	231	233	192	138
170	135	164	129	171	186	158	178
296	222	249	225	234	246	236	231
.	.	290	301	305	291	332	.
.	.	307	347	355	355	388	.
.	.	407	404	415	378	357	.
346	285	346	314	318	301	234	321
392	268	312	339	337	336	216	333
330	415	307	290	309	323	198	319
418	376	331	350	365	357	287	317
420	327	267	321	344	349	298	321
383	390	408	392	380	392	305	278
430	385	246	284	296	313	316	319
365	435	400	395	420	333	338	342
190	243	219	215	254	248	251	248
390	202	277	304	334	314	291	227
268	204	149	149	141	159	143	156
310	301	325	314	326	304	285	285
88	37	52	98	96	120	160	257
27	35	87	79	111	118	232	267
130	175	328	323	319	338	348	378
219	283	232	214	222	232	245	256
288	230	173	223	233	231	237	278
298	247	225	214	232	256	254	267
433	349	358	377	427	284	336	428
396	400	415	288	321	367	309	308
321	360	371	261	347	261	302	324
346	164	237	274	291	287	322	320
190	56	215	197	211	213	164	189
201	284	239	213	241	256	155	154
242	143	75	220	208	198	212	241
353	389	323	217	349	332	303	323
240	291	322	279	326	343	355	354

Table H.2. Emergence count data under different tillage treatments at Faisalabad

Trt.	Rep.	Rows	No of Plants/Sq.m. Days after planting 7	8	9	10	11
C	1	1	0	0	23	100	105
C	1	2	0	0	0	0	0
C	1	3	0	0	0	5	7
C	2	1	0	3	8	36	236
C	2	2	0	3	67	78	151
C	2	3	0	14	114	124	145
C	3	1	0	1	25	75	100
C	3	2	1	5	15	65	52
C	3	3	0	5	22	36	103
R	1	1	0	0	0	0	0
R	1	2	4	40	23	45	87
R	1	3	0	10	100	125	187
R	2	1	15	55	275	280	284
R	2	2	0	10	96	110	220
R	2	3	10	78	223	239	260
R	3	1	0	0	9	115	111
R	3	2	0	2	38	36	200
R	3	3	0	1	24	85	145
D	1	1	28	909	200	228	255
D	1	2	23	61	154	189	217
D	1	3	15	80	160	160	170
D	2	1	4	20	100	198	216
D	2	2	35	58	142	72	324
D	2	3	38	98	172	78	100
D	3	1	50	97	250	270	276
D	3	2	55	98	274	296	298
D	3	3	46	73	210	225	235
M	1	1	56	171	200	215	248
M	1	2	72	113	280	298	226
M	1	3	51	95	313	332	334
M	2	1	15	122	132	139	168
M	2	2	16	90	200	205	220
M	2	3	25	96	187	192	260
M	3	1	59	88	200	215	245
M	3	2	23	121	300	321	250
M	3	3	38	98	266	271	280

12	13	14	15	16	17	18	19	20
166	169	173	173	181	248	289	289	289
0	0	0	0	0	32	86	108	108
16	250	270	278	281	344	360	360	360
280	283	292	301	301	422	439	321	446
200	227	232	239	239	391	402	409	409
169	178	186	202	165	212	301	446	335
147	156	162	180	189	423	440	442	442
105	115	179	319	240	244	249	249	249
150	161	165	330	186	365	372	374	346
0	0	0	0	0	2	30	41	41
91	99	104	120	141	323	324	329	329
190	198	205	212	225	481	481	481	486
300	327	369	382	385	370	391	391	391
301	320	343	354	358	355	387	387	387
341	358	371	372	375	403	423	413	413
112	112	126	139	149	355	392	392	398
250	262	271	278	281	490	490	492	493
216	223	231	239	242	514	520	522	522
260	263	269	273	278	475	486	488	489
240	246	248	256	290	445	461	466	468
180	~~186~~	~~189~~	~~102~~	~~161~~	~~380~~	~~386~~	~~398~~	399
221	223	224	232	241	535	535	535	538
350	354	356	302	376	511	516	516	520
120	123	124	132	186	505	505	505	505
280	306	312	305	305	387	389	400	402
300	288	289	321	324	410	421	421	425
285	290	299	310	321	165	280	310	312
300	318	323	333	336	426	426	432	432
302	322	328	335	338	423	435	440	440
340	349	354	358	362	425	440	440	443
200	206	210	223	228	495	495	495	496
286	289	293	299	309	426	428	430	432
270	273	277	286	291	418	418	422	422
260	264	270	239	289	513	513	519	519
300	309	309	319	320	447	474	474	474
304	316	318	330	340	447	456	458	458

Table H.3. Emergence count data under different tillage treatments at Pirsabaq

			No of Plants/Sq.m.				
			Days after planting				
Trt.	Rep.	Rows	7	8	9	10	11
C	1	1	169	250	267	250	330
C	1	2	166	150	267	275	325
C	1	3	174	200	268	300	335
C	2	1	213	165	195	250	345
C	2	2	280	110	220	245	335
C	2	3	275	120	250	275	340
C	3	1	215	120	184	250	355
C	3	2	165	165	184	280	365
C	3	3	125	275	184	285	370
R	1	1	34	145	183	330	385
R	1	2	313	135	237	350	365
R	1	3	170	200	243	335	345
R	2	1	180	250	250	286	280
R	2	2	185	100	245	245	285
R	2	3	175	275	250	250	340
R	3	1	220	300	250	250	330
R	3	2	230	350	290	280	335
R	3	3	235	200	245	285	340
D	1	1	160	250	194	225	345
D	1	2	170	310	200	245	385
D	1	3	225	180	23	240	300
D	2	1	230	150	193	250	355
D	2	2	200	110	194	280	360
D	2	3	300	170	195	300	370
D	3	1	200	165	267	300	355
D	3	2	190	215	268	290	360
D	3	3	206	250	245	245	365
M	1	1	188	110	240	300	355
M	1	2	187	165	268	250	340
M	1	3	189	220	245	275	345
M	2	1	265	140	210	355	355
M	2	2	220	195	215	310	370
M	2	3	275	150	240	360	345
M	3	1	250	250	229	300	345
M	3	2	170	300	233	305	340
M	3	3	220	200	188	255	345

12	13	14	15	16	17	18	19	20
250	260	334	364	368	366	374	376	338
250	265	341	339	359	360	358	361	331
300	270	315	271	284	291	287	293	347
250	275	322	223	335	326	328	329	425
275	280	324	292	308	311	312	319	560
280	295	333	344	351	348	348	359	550
315	355	334	341	360	360	357	363	430
295	360	304	373	398	401	404	410	330
305	365	311	319	327	329	330	334	250
250	250	302	275	288	280	290	291	67
245	280	309	324	313	316	325	331	625
240	260	316	307	415	413	412	420	340
210	300	316	311	313	322	324	333	360
215	305	327	330	340	336	339	341	370
220	310	333	346	364	359	356	366	350
315	330	331	337	343	344	341	339	440
320	335	304	344	356	363	371	367	460
310	315	311	371	375	367	369	368	470
250	300	349	340	348	354	359	354	320
252	330	342	367	368	370	378	385	340
255	335	337	328	238	241	243	243	450
348	250	299	346	369	366	367	377	460
342	280	327	334	345	346	349	349	400
337	285	310	285	297	299	306	317	600
360	295	322	275	267	273	273	278	400
355	290	332	370	393	394	391	395	380
365	285	342	357	378	374	377	378	411
216	315	343	313	314	316	319	322	375
220	320	341	296	315	310	311	323	374
230	290	321	308	310	318	309	318	377
330	330	302	331	327	334	332	337	530
335	335	309	363	372	376	376	380	440
320	320	316	298	305	304	313	317	550
315	300	317	319	324	325	324	330	500
310	335	308	359	365	364	362	359	340
320	330	326	325	328	331	333	332	440

Table H.4. Analysis of variance of emergence count

Source	DF	Islamabad	Faisalabad	Pirsabaq
		F-values		
Trt.	3	2.23	4.11**	< 1
Rep(trt) Error (a)	8	--	--	--
Loc(trt*rep) Error (b)	24	--	--	--
Days	12	3.74***	86.30***	46.35***
Trt*days	36	< 1	< 1	< 1
Rep*days(trt) Error (c)	96	--	--	--
Error (d)	288	--	--	--
Corr. Total	467			

*Significant at 0.10 probability level.
**Significant at 0.05 probability level.
***Significant at 0.01 probability level.

APPENDIX I: YIELD AND YIELD COMPONENTS DATA

Table I.1. Yield and yield components data obtained under different tillage treatments at Islamabad

Trt.	Rep.	Loc.	Ears per Sq.m (g)	Yield per Sq.m (g)	Yield per 25m (kg)	Weight per 1000 grain (g)
C	1	1	313	502	6.20	48
C	1	2	239	410	.	46
C	1	3	255	621	.	.
C	2	1	263	495	7.60	43
C	2	2	211	332	.	48
C	2	3	312	483	.	.
C	3	1	307	532	9.35	46
C	3	2	255	485	.	44
C	3	3	416	323	.	.
R	1	1	218	346	10.07	50
R	1	2	356	590	.	50
R	1	3	141	428	.	.
R	2	1	295	456	8.15	48
R	2	2	371	498	.	47
R	2	3	379	523	.	.
R	3	1	344	622	11.40	46
R	3	2	256	534	.	48
R	3	3	285	708	.	.
D	1	1	272	440	9.85	46
D	1	2	176	381	.	46
D	1	3	208	609	.	.
D	2	1	238	597	11.06	50
D	2	2	210	664	.	48
D	2	3	212	512	.	.
D	3	1	308	624	8.80	49
D	3	2	308	536	.	50
D	3	3	271	331	.	.
M	1	1	290	672	10.61	50
M	1	2	255	645	.	52
M	1	3	222	604	.	.
M	2	1	258	532	8.75	48
M	2	2	336	461	.	48
M	2	3	313	750	.	.
M	3	1	324	660	11.95	49
M	3	2	298	708	.	50
M	3	3	191	724	.	.

Table I.2. Yield and yield components data obtained under different tillage treatments at Faisalabad

Trt.	Rep.	Loc.	Ears per Sq.m (g)	Yield per Sq.m (g)	Yield per 25m (kg)	Weight per 1000 grain (g)
C	1	1	270	229	8.50	36
C	1	2	297	324	.	38
C	1	3	.	370	.	.
C	2	1	250	434	8.70	38
C	2	2	349	348	.	38
C	2	3	.	449	.	.
C	3	1	326	421	10.50	44
C	3	2	221	257	.	42
C	3	3	.	448	.	.
R	1	1	233	344	9.80	48
R	1	2	310	530	.	46
R	1	3	.	321	.	.
R	2	1	285	423	9.80	46
R	2	2	275	334	.	44
R	2	3	.	370	.	.
R	3	1	280	511	8.30	48
R	3	2	365	440	.	48
R	3	3	.	461	.	.
D	1	1	270	520	10.70	50
D	1	2	190	336	.	48
D	1	3	.	276	.	.
D	2	1	245	386	10.50	46
D	2	2	323	397	.	48
D	2	3	.	558	.	.
D	3	1	346	401	10.20	40
D	3	2	260	297	.	44
D	3	3	.	440	.	.
M	1	1	268	408	9.80	46
M	1	2	246	401	.	48
M	1	3	.	307	.	.
M	2	1	267	511	11.00	52
M	2	2	280	450	.	54
M	2	3	.	354	.	.
M	3	1	302	496	12.00	50
M	3	2	287	378	.	48
M	3	3	.	477	.	.

Table I.3. Yield and yield components data obtained under different tillage treatments at Pirsabaq

Trt.	Rep.	Loc.	Ears per Sq.m (g)	Yield per Sq.m (g)	Yield per 25m (kg)	Weight per 1000 grain (g)
C	1	1	279	534	13.81	42
C	1	2	288	539	.	39
C	1	3	.	548	.	.
C	2	1	353	573	18.28	39
C	2	2	347	692	.	41
C	2	3	.	583	.	.
C	3	1	303	372	11.90	43
C	3	2	381	596	.	42
C	3	3	.	608	.	.
R	1	1	234	336	8.29	47
R	1	2	263	312	.	49
R	1	3	.	354	.	.
R	2	1	322	388	11.05	51
R	2	2	360	639	.	48
R	2	3	.	587	.	.
R	3	1	395	642	15.30	50
R	3	2	309	430	.	49
R	3	3	.	342	.	.
D	1	1	359	664	11.90	48
D	1	2	337	408	.	46
D	1	3	.	431	.	.
D	2	1	347	707	19.55	44
D	2	2	330	612	.	47
D	2	3	.	468	.	.
D	3	1	325	451	13.60	48
D	3	2	378	603	.	46
D	3	3	.	500	.	.
M	1	1	308	416	14.45	53
M	1	2	396	497	.	50
M	1	3	.	613	.	.
M	2	1	380	623	18.70	49
M	2	2	381	631	.	51
M	2	3	.	710	.	.
M	3	1	258	584	12.75	51
M	3	2	352	456	.	50
M	3	3	.	591	.	.

Table I.4. Analysis of variance of wheat yield

Source	DF	Islamabad	Faisalabad	Pirsabaq
		F-values		
Method 1				
Trt.	3	4.74^{***}	< 1	2.73^{*}
Rep(trt) Error (a)	8	1.20	< 1	1.59
Error (b)	24	--	--	--
Corr. Total	35			
Method 2				
Trt.	3	1.93	2.67	< 1
Error	8	--	--	--
Corr. Total	11			

*Significant at 0.10 probability level.
**Significant at 0.05 probability level.
***Significant at 0.01 probability level.